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Bulletin of the Museum of Comparative Zoölogy

AT HARVARD COLLEGE.

Vol. XXVIII. No. 1.

(Geological Series, Vol. III.)

FOSSIL SPONGES OF THE FLINT NODULES IN THE LOWER CRETACEOUS OF TEXAS.

By J. A. Merrill.

With One Plate.

CAMBRIDGE, MASS., U. S. A.:

PRINTED FOR THE MUSEUM.

July, 1895.

No. 1. — *Fossil Sponges of the Flint Nodules in the Lower Cretaceous of Texas.* By J. A. MERRILL.[1]

THE following investigation was undertaken as thesis work in the course in Palæontology in Harvard University, at the suggestion of the instructor, Dr. R. T. Jackson. As the study proceeded, its importance became more apparent and it was thought advisable to extend the work somewhat and publish it. With the advice and assistance of Professor N. S. Shaler, therefore, careful revision has been made and the results here presented. So far as I have been able to ascertain, the minute structure of the cretaceous flints of America has never been studied except in a general way, and nothing whatever has been published on the microscopic organisms composing them. The field is therefore a large as well as a fascinating one, and this effort is intended only as a beginning of what is hoped will prove a fruitful line of inquiry. The flint nodules from which specimens were taken for study were collected in a quarry near Austin, Texas, and brought to Cambridge by Mr. Edward E. Cauthorne. They vary greatly in shape and size ; and, owing, perhaps, to small areas of calcite scattered through the mass, they vary somewhat in hardness. The hardness is often greater than that of glass, and the flint will generally scratch glass. In shape they are spherical, cylindrical, or flat ; and in size they vary from two inches to a foot or more in diameter. The color is a dense black, with white or gray spots mixed irregularly through it, varying in size from microscopic to that of a pin-head. These spots are generally replacements of organic remains, and, when such, are, in all cases that I examined, chalcedonic silica ; the larger ones showing the concentric structure characteristic of chalcedony. Some of them, however, have shapes so irregular and outlines so indefinite, that they cannot be referred to any particular organic form, although they are most likely replacements. All the spots of calcite examined are small and indefinite in form and outline. They are called calcite because of their behavior in polarized light. The outside of the nodule is composed of a layer of chalk about one quarter to three quarters of an inch

[1] Contributions from the Geological Laboratory of the Museum of Comparative Zoölogy, in charge of N. S. Shaler.

in thickness, cemented with infiltration of silica. Generally, there is but one layer of chalky substance, but in one nodule I found four, alternating with layers of solid, amorphous silica giving the whole the ringed appearance of a concretion of sand or clay.

Of the occurrence and appearance of these nodules *in situ*, I quote the following from the First Annual Report of the Geological Survey of Texas, by Professor Robert T. Hill (pp. 124, 125) : "These flint nodules are found in the Caprina chalk and chalky limestone subdivision of the Comanche Series of the Cretaceous of Texas. . . . They are oval and kidney-shaped, ranging in size from that of a walnut to about two feet in diameter. Exteriorly they are chalky white, resembling in general character the flint nodules of the English chalk cliffs. Interiorly they are of various shades of color from light opalescent to black, sometimes showing a banded structure. . . . The fact that these are the only flint horizons, so far, at least, as is known to the writer, in the whole of the immense cretaceous deposits of the United States, is very interesting, and especially since they occur about the middle of the Lower Cretaceous Series, instead of the top of the Upper Series as in England."

The nodules of Comanche County, according to Professor Hill, contain a nucleus, *Monopleura Texana*, around which the flint has formed, but in the nodules that I examined the silica was solid throughout and there were no nuclei of any kind. The work herein described was confined largely to three nodules, which were prepared in the following way. Thin sections were cut and mounted in Canada balsam, just as rock slides are made for petrographical study. These sections were made at the circumference and near to the centre, perpendicular to the surface and approximately parallel to it. In addition to these, several slides were made at random in each nodule. This precaution was observed in order that the difference in preservation of organic remains between the interior and surface might be detected, if present. The sections were cut at different angles to detect if there be a tendency toward definite arrangement of organic remains in the nodule, — a tendency which might result from the constant application of any external force unchanging for even a short period of time. Caustic potash and acids were tried in identifying the mineral material of the replacement, but on account of the very hard nature of the mass of the nodule, it was found best to use the polarizer only, which produced more satisfactory results. During the progress of this work, I have been the recipient of favors from Dr. Robert T. Jackson and the Boston Society of Natural History, both of which it is my pleasure to acknowledge.

A Statement of the Questions Involved.

A detailed statement of the questions involved in this inquiry may be of service in directing the mind to the result from the beginning, thus placing before the reader the distinct line of thought to be followed. The excellent work done on cherts and flints by Carter, Sollas, and Hinde in England, and Zittel and others on the Continent, has conclusively shown that the source of these stones is organic silica, and that the principal source of this silica is the framework of siliceous sponges. I have therefore assumed this origin for the silica of the flint nodules under consideration.

This conclusion appears admissible from the great similarity of physical characteristics of nodules and surrounding materials in the Cretaceous of Europe and America, and also from the fact that the included fossils are of the same families and genera. The identity of origin assumed, there is still left for us the profitable task of the identification of the organic forms, and the comparison of them with the known forms of Europe. The following topics, therefore, will be discussed in the order given: —

1. The identification of the fossils of the groups of animals represented. These fossils cover rather a wide range and are significant as well as interesting.

2. As fossils of sponge spicules are the principal organic remains, attention is next drawn to a consideration of the condition of preservation and character of replacement of these spicules. The forms of spicules are then taken up and classified to the genus, where it is possible, by comparison with work done by others in this subject.

3. Since the microscopic structure of flint nodules has not been studied before, it would seem that the question of condition and process of formation might receive some attention. If we suppose that the nodules are segregations of materials from many sponges, collected around a nucleus which occupies a position near the centre, then all the spicules from centre to circumference would show considerable mechanical wear as the result of concretionary formation. On the other hand, if we suppose the nodules to have been formed at the base of a cluster of growing sponges, which die in all stages of development, then the spicules of sponges *in situ*, so far as they have escaped the process of solution, will be perfectly preserved; while the spicules from the surrounding sponge areas washed in by motion of the water, will show more or less mechanical wear. In this case a foreign body as

nucleus may or may not be present. It is evident also that different nodules may have been formed in different ways, and hence we shall confine our conclusions to the limits of our observations.

4. In the summary we shall discuss the bearing of this study on the depth and condition of deposition of the chalk of the surrounding formations.

Organisms found in the Flint.

Slides taken from the same nodule were found to present great similarity of kinds of organisms, but great difference in size. A species of spicule, for instance, is often found in all stages of development in the same slide. Different nodules, however, show great variation in the prevailing kinds of orgánisms and the condition of their preservation. On the whole, however, the number of organic remains is few, and the massive silica greatly in excess. When viewed with high power of microscope, this massive portion appears often to consist of aggregations of minute granules varying in color from brown to almost colorless. Dr. Hinde[1] found the same true in cherts of the Greensand, and speaks of the granules as having "circular outlines, though not strictly a spherical form." Chalcedonic masses with their characteristic concentric structure are common in some of the nodules and rare in others. Many traces of organisms, the outlines of which were but dimly shown, were not made out; but those determined were of the groups given below.

1. Foraminifera. These were found in every slide examined, and were quite numerous in one of the nodules. The types found were principally of the family Globigerina, of which several different species were common. Textularia were found in most of the slides, though not so common as Globigerina, and several other families were found occasionally. These forms were generally replaced by amorphous silica, the outlines remaining in a dark substance which has the appearance of organic residue. Globigerina were also found replaced in chalcedonic silica, but the outlines and structure of the chalcedonic mass almost obliterated the form of the fossil.

2. Sponges. In two of the nodules the spicules were of frequent occurrence, but not very abundant; but in one nodule of which I had two sections, not a distinct trace was found, except occasionally a small fragment of the spicule of a Monactinellid shown in Figure 7. The minute dermal spicules are, generally speaking, better preserved than the

[1] Sponge Remains of Lower and Upper Greensand, Phil. Trans. Royal Society, Part II., 1885, p. 427.

zone spicules; and are therefore present in greater numbers. These will be discussed in detail later.

3. Mollusks. Small fragments of what I thought nacreous and prismatic tissue of shells of mollusks were found in two of the nodules. The condition of their preservation was not sufficiently perfect, however, to make their identification absolutely certain. They are replaced by amorphous silica, which in taking their structure has been turned a bright transparent yellow.

4. Fishes. Several organisms having the general form of fish scales were found, but no attempt has been made to identify them with modern or fossil fishes. They are of a bright transparent yellow, and have the appearance of organic silica. Their surfaces are perfectly smooth, and the outline entire and complete. In the polarizer they show no effect different from that produced by the amorphous silica surrounding them. I concluded, therefore, that they are amorphous silica similar to the shell fragments previously described.

Condition of Preservation of the Sponge Spicules.

Spicules are found in these flints in all stages of preservation. But few were found perfect except the globo-stellates and similar spicules of the dermal layer. Occasionally, areas in the slide were found containing numerous faint tracings of spicules which are so merged together that they cannot be separately traced. More often, however, they are separately embedded in a mass of amorphous silica. Under the high power of the microscope, except in cases where the spicules seem to end indefinitely in the surrounding silica, the outline is perfect, but more or less ragged, owing to the irregularities of replacement. The canal often shows a separate crystallization from the body of the spicule, and is generally smooth in outline. The canal differs greatly in size in the different specimens, and in some occupies the entire body except a small ring of crystalline silica on the outside. Apparently the replacement began along the axial canal at the same time as it did on the surface, and in some cases, as in Figure 5, it seems that most of the spicule has been replaced from the inner side.

In this spicule, and also in others, the canal seems to be replaced with a dark opalescent silica mixed with grains of siliceous sand. Replacements with sandy material are common in the English flints. In other spicules the canal is perfectly transparent and hyaline in appearance, and in a few cases the canal is not continuous (see Figure 1). In

those spicules that have canals the polarizer shows plainly two distinct areas of crystallization, the outer one being the more perfect. In those spicules that have no separate replacement of the canal, the whole spicule is replaced by amorphous silica, generally of an opalescent hue.

The globo-stellates and other spicules of the dermal layer present a somewhat different appearance. In many cases these spicules are entirely perfect, the globule, the spine, and the minute barbs being perfect in all their microscopic details. The color of these spicules varies from a light brown to a dark yellow, all more or less transparent, and some of them quite so. In polarized light these have the same properties as the amorphous silica, with the exception of color and a higher single refraction. One case was found where the globo-stellate had been replaced by crystalline chalcedonic silica, but it was imperfectly preserved, and the barbs on the spines were so short and poorly finished that it was not possible to figure it. This fact clearly shows us that we must suppose either that the spicules have been replaced by amorphous silica, or that they are still in the hyaline or colloidal state as formed, and colored yellow by some organic agent perhaps. While this latter supposition seems most reasonable from the facts considered, yet if such be the case it would seem probable that some spicules would be found partly replaced with crystalline silica, a phenomenon which was not discovered. However, before we admit this doubt to its full value, it is necessary to remember that the field of observation was extremely limited, and that such may exist in sufficient number to show all stages of replacement. I shall designate this transparent yellow condition of the spicules as colloidal silica, for want of a better term, at the same time recognizing the fact that it has changed considerably in color from the original condition in which it was secreted by the animal.

While the preservation of many of the globo-stellates is perfect, even to the showing of the minute spines and barbs in the proper relation to the globate centre, yet some of them appear in a more or less fragmental condition, which reveals an interesting fact in their history. Some show the spines and barbs bent slightly toward the central body, as in Figure 12; in others the barbs are broken off or otherwise removed, and are missing entirely; while in others the globate portion is broken and part of it removed, as in Figure 13. How much of this breakage and removal is due to mechanical force it is difficult to say, for there is evidence that at least part of it is due to solution. It appears that the globular centre is dissolved more quickly and easily than the spines, but it is plain that the spines will yield first to any mechanical force. Sollas found by

experiment[1] that the globo-stellates dissolved from within outwards, and the central cavity enlarged from within outwards, until the outer covering became a mere film. The spicule shown in Figure 22 is a good illustration of this fact in nature. The middle portion, not figured, is detached from the spines, and has almost entirely disappeared, leaving the spines surrounding the centre in the position formerly sustained.

This is plainly a case of solution in which the spines have survived the globate centre. It is a peculiar fact, also, that although much of the spicule has been dissolved, yet there has been no replacement by crystalline silica, but the surrounding amorphous silica shows no trace of the original outlines of the dissolved portion. This may also explain the fact that the spicules (Figs. 1 and 2) merge so gradually into the surrounding amorphous silica that it is impossible to tell exactly where the spicule ends. It thus seems to occur frequently that the spicule is dissolved, and redeposited as amorphous silica without definite form.

Professor Sollas says that "spicules of sponges are colloidal because of spiculin, and being dissolved they lose their spiculin and are redeposited as crystalline silica, and may be amorphous or chalcedonic."[2]

The solution and redeposition of masses of spicules is a simple process, but the principle, if there be one, that enables some to be replaced while thousands are entirely dissolved, is more difficult to determine. The flesh spicules seem to have resisted the processes of solution better than the others, and are more numerous, as well as more perfect in all the slides examined. These small flesh spicules are not common in the deposits of England.[3] Their abundance and perfection in the flints of Texas, therefore, indicate a difference in the surrounding conditions that is not altogether apparent. Another form of fossil spicule, more rare as a whole, but common in some of the nodules, is replacement by peroxide of iron. This is not found continuous throughout a whole spicule, but is usually an irregular, disconnected chain of dark bead-like masses. These masses are generally globular in shape, but often elongated and tapering at one end. Similar replacements have been described by Dr. Hinde,[4] and have also been referred to by others. These spicules occur in various degrees of completeness, the most perfect found being Figure 34, in which there seems to be a peculiar mixture of amorphous silica and peroxide of iron alternating, thus giving the spicule a spotted appear-

[1] Annals and Magazine of Natural History, Ser. 4, 1877, Vol. XX. p. 229.

[2] Ibid., Ser. 5, 1880, Vol. VI. p. 445.

[3] Ibid., Ser. 4, 1871, Vol. VII. p. 122; also Ser. 5, 1880, Vol. VI. pp. 441, 442.

[4] Catalogue of Fossil Sponges of the British Museum, p. 6.

ance. In spicules replaced by peroxide of iron, or wholly by amorphous silica, the canal is not usually shown. An exception is found, however, in Figure 5, in which the canal is replaced by the ore.

Comparison with English Chert.

During the progress of this work I have been so fortunate as to receive from Dr. Robert T. Jackson a piece of chert collected in England by Dr. C. E. Beecher, of New Haven, Connecticut. This chert, I am informed by Dr. Beecher, was collected at Croydon, England, but the geological position was not stated, and its exact horizon is not known. I thought, however, that a comparison of this with the Texas flint might give a clearer notion of the character and composition of the Texas flints, especially to those who have studied the cherts of England. The chert is a light brown to dark brown color, which contrasts strongly with the dense black of the flints; it is much softer, and contains numerous small patches, and some large areas of crystalline calcite. The appearance in the microscope is quite different on the whole, although similar in some respects. The chert did not have that granular amorphous silica so common, as did the flints, but instead it seemed to be composed of a dense aggregation of spicules so entangled and interlaced that it is almost impossible to find a spot where there are not dozens in the field of the microscope.

In the chert the spicules are much more perfect in form, and, as a rule, they are replaced by a crystalline silica or peroxide of iron. Several cases were noticed where the entire replacement was by a chalcedonic silica so perfectly transparent that they have a hyaline appearance. The remains of Protozoans in the flint, as has been said, are few, and are replaced chiefly by arenaceous, amorphous silica; while in the chert, protozoans, chiefly foraminiferous, are abundant, and are generally replaced by chalcedonic silica.

In the whole piece of chert (four slides were examined) only one globo-stellate was found, and that one had large centre and short straight spines somewhat similar to Figure 16 of these flints. One siliceous ball was found, but none of the smaller dermal spicules, although acuates, trifids, quadradiates, etc. of every size and form were present in great numbers, crowded together in heterogeneous masses. The differences between the chert and the flint seem difficult of explanation, unless it be that the chert was formed more rapidly than the flint, and there was less time for solution and solidification.

Classification of the Spicules.

A complete system of classification of fossil sponges was first successfully attempted by Professor Zittel in 1877, on the basis adopted for the classification of recent sponges by Oscar Schmidt. Since that time much work has been done in England by Messrs. Carter, Sollas, and Hinde, and on the Continent by Zittel and various others. As no work has been done on the flints of America, I found many forms not figured in fossil studies, so that I have been compelled to study the works of Schmidt, Bowerbank, Sollas, and Carter, and the Reports of H. M. S. "Challenger" on recent sponges, in order to locate them. More than half of the forms studied have never been found fossil before, and I have classified them by comparison with both fossil and recent forms. Some of them I have been able to locate no further than the family, and others to the genus. Some of these forms, especially of the Monactinellids, I have traced as far as I could with the literature available, but have not felt competent without type fossils and more research to suggest scientific names. However, I have figured them and referred them where possible to genera, in the hope that they may be used for reference.

In the Tetractinellids, the globo-stellates are so widely different from anything described or figured, either fossil or recent, that I have thought it allowable, and even necessary, to give them specific names, in order that they may be referred to more accurately. However, it must be remembered that every sponge has two or more kinds of spicules, and when they are detached, it is a matter of great difficulty to combine them with sufficient accuracy for reliable classification.

I am aware also that the globo-stellates are not considered of much value in determining the classification of recent sponges; but as spicules of this type are so prominent in the Texas flint, it is desirable, it seems, to name them without regard to the combination of spicules necessary to define the species. It is possible that two or more of the spicules to which I have given specific names belong to the same species of sponge, but this there can be no way of finding out at present. The names are therefore proposed in the hope that they may be useful in the study of Texas flints. Only the largest and most perfect spicules have been figured, because I hoped thus to get the adult form. The measurements were taken with the utmost care with a micrometer. The classification of the orders which follow has been taken from Professor Zittel's "Fossile Spongien," and most of it from the translation by W. S. Dallas in

Annals and Magazine of Natural History.[1] References to other works are cited at the places where quotations occur, in order that investigation of authorities may be handier for those who desire to follow the line of thought.

MONACTINELLIDÆ, Zittel.

To this group Zittel refers all sponges the framework of which consists of simple uniaxial siliceous spicules. It is regarded by him as a small and unimportant group in the fossil state. The spicules referred to it are frequently so much like the zone spicules of other groups that it is extremely hard to separate them, and to decide whether the spicule in question belongs to Monactinellidæ or some other group which has spicules of a single shaft. The acuate spicules that I have referred to this group have been so referred mainly on their similarity in size and shape to those figured by Dr. Hinde.[2]

Figures 1 and 2. Axinella? Imperfect. Replaced by chalcedonic silica. Canal well shown, polarizes differently from the body, showing a separate crystallization. Summits rounded. Body slightly curved, but tapering toward the point. Size of Figure 1: length, 0.733 mm.; width, 0.08 mm. Size of Figure 2: length, 1.673 mm.; width, 0.133 mm. These spicules are perhaps some form of Axinella. Dr. Hinde has called a similar one *Axinella dispersa*.[3] These forms are not rare in the nodules, but are never found perfect.

Figures 3 and 4. Reniera? Conical spicules even in outline, with axial canals well shown. Bases broad, tapering gradually to apex. Replacement is by crystalline silica. Size of Figure 3: length, 0.373 mm.; width, 0.093 mm. These are probably some form of Reniera. Similar figures, but larger, are found in the Upper Chalk,[4] and also in the Upper and Lower Greensand.[5]

Figure 5. An acuate spicule in amorphous silica surrounded by a thin layer of chalcedonic silica. Length, 0.64 mm.; width, 0.08 mm. Similar spicules have been figured by Hinde.[6]

[1] Ser. 4, Vol. XX., and Ser. 5, Vols. II. and V.

[2] Fossil Sponges of the Upper Chalk and Sponge Remains of the Upper and Lower Greensand, Phil. Trans. Royal Soc., 1885, Pt. II.

[3] Phil. Trans. Royal Soc., 1885, Part II., p. 437, Plate XLI. Figs. 6–6e.

[4] Fossil Sponge Spicules, p. 23, Plate I. Figs. 19 and 20.

[5] Phil. Trans. R. S., Pt. II., 1885, p. 22, Plate XLI. Fig. 1a.

[6] Fossil Sponges of Upper Chalk, pp. 20, 21, Plate I. Fig. 14.

Figure 6. Imperfect. This spicule has been replaced by amorphous silica of an opalescent hue, the dark portion of which represents the replacement of the axial canal enlarged. It is covered with bulbous projections or blunt spines, which are evenly arranged toward the apex, but become more irregular toward the extremity. It has the appearance of being thin and flat rather than cylindrical. It is 0.0843 mm. long, by an average width of 0.0844 mm. It has not been found figured.

Figure 7. This spicule is imperfect and irregular in outline, the irregularity seemingly composed of folds in the outer covering of the spicule. The outline seems to be in peroxide of iron, or some kind of black organic matter, most likely the latter, since it has not the beaded form common to the ore replacement. The interior is entirely of amorphous silica, with a trace of an axial canal. A cross section of this shows a thin black ring around a siliceous body. This figure is 0.52 mm. in length by 0.08 mm. in width. This species is the most abundant of the sponge spicules found in the flint, and the figure given represents its most characteristic form. The summit of one has not been found, and only occasionally is the apex found complete, while fragments and cross sections are abundant. It was found in all the nodules examined, and one was made up almost entirely of it. In the nodules above referred to there are found what appeared to be irregular black tracings of the outside layer of this spicule, curiously winding around in the flint and giving it a dark ringed appearance. This outside layer is sometimes thicker than others, but is always distinct, and surrounds the spicule entire unless broken mechanically. I have not found this spicule described or figured.

Figure 8. A fragment of a cylindrical spicule covered with very short bulbous projections. The specimen is composed of a thin wall of colloidal silica, while the inside is filled with whitish amorphous silica, no axial canal visible. Size of specimen: length, 0.266 mm.; width, 0.106 mm. Of this I found but one specimen. One somewhat similar is figured by Dr. Hinde.[1]

Figure 9. Esperites? sp. Almost perfect, but the ends not fully shown. A bihamate spicule. Length, 0.266 mm., width, 0.026 mm. Others found measure 0.386 mm. in length by 0.026 in width. Others less typical in size show the peculiar bihamate ends better than the one figured. This is a very common form in the nodules, and is found in nearly every slide. It is probably some species of the recent family

[1] Fossil Sponges of Upper Chalk, Plate I.

Esperia, and similar to *Esperites haldonenses* Carter.[1] Fossil forms have also been figured by Hinde.[2]

Figure 10. Reniera ? sp. This spicule is replaced on the outside by chalcedonic silica, and part of the inside by peroxide of iron. Length, 0.26 mm., width, 0.013 mm. It may be referred to some form of Reniera similar to but smaller than *Reniera Zittelli*, Pocta, figured by Hinde.[3] This is not an uncommon form in the flints.

Figure 36. Reniera ? sp. Outline perfect. Has typical form of Reniera. Curved, cylindrical, and rounded similarly at the ends. Length 0.48 mm., width 0.106 mm. It is replaced by amorphous silica. This is a common form here and also in Europe. Figured by Hinde.[4] This specimen was found on the outer margin of the nodule embedded in the silicified chalk. It is rather larger than the average of its kind.

TETRACTINELLIDÆ, Marshall.

This order contains sponges with skeletal spicules of the pyramidal type. In addition to those which are the principal or zone spicules, there are dermal or flesh spicules which are characteristic of the living forms, but which are rarely ever found fossil. These last are most abundant in the Texas flint nodules. Of the first, several were found generally imperfect, the one shown in Figure 32 being the smallest in size, but most perfect in form and condition of preservation. The spicules of the flesh and dermal layers are of various forms and have received various names. They were first thought by Bowerbank to be the reproductive system and were called siliceous balls; they were afterwards called globular crystalloids, spino-globates, and globo-stellates by Carter. They are all more or less circular in outline, and many are globular, and nearly all are covered with spines. Four varieties were found in the slides examined ; the thin, smooth, circular transparent disk ; the spino-globate, Figure 30, flat, with spines apparently around the periphery only; the globo-stellate with the spherical centre and short simple spines ; and the globo-stellate with spherical centre and long spines divided into barbs at the end.

The last two divisions named are peculiar from the fact that the spines are hollow tubes branching from the hollow centre, thus allowing,

1 Ann. Mag. Nat. Hist., Ser. 4, 1871, Vol. XII. p. 131, Plate IX. Fig. 43.

2 Phil. Trans. R. S., Part II., 1885, p. 437, Plate XLI. Fig. 12.

3 Ibid., 1885, p. 437, Plate XLI. Figs. 4–4e.

4 Fossil Sponges in the Upper Chalk, p. 23, Plate I. Fig. 17.

apparently, communication of the centre with the outside. As has been mentioned, these spicules have not been replaced, but are most likely still in the original colloidal condition. The bright transparent yellow color is perhaps due to a change brought about bythe action of some organic acid which may be a beginning of the replacement process. When viewed with high power lens, these bright yellow spicules, radiating in perfect symmetry from the hollow centre, are exceedingly beautiful, and in their various forms present a contrast both novel and interesting. These all belong to the family Geodidæ, Lamarck, and with one or two exceptions none of them have been figured as fossil, but most of them are similar to the recent forms referred to in the description. In the Fossil Sponges of Upper Chalk, Dr. Hinde figures a globo-stellate spicule, body ornate and covered with short sharp spines. This is, however, much larger than the spicules of thè Texas flint. Professor Zittel also figures two globo-stellates, somewhat similar in form to Figure 16 of the Texas flints.[1] They are much larger, however, and none have been found with barbs on the ends of the spines. This may be due to the fact of imperfect preservation, but it would seem from the number of specimens examined some indication at least of barbs would have been detected if present.

In Oscar Schmidt's "Die Spongien des Atlantischen Gebietes" nothing is given similar to the globo-stellates of the Texas flints. In his "Sponges of the Adriatic Sea," however, he figures globo-stellates of Geodia placenta.[2] These have spherical bodies with round straight spines, but they are much larger. The measurements given were taken from tip to tip of spines at right angles to each other, and then the length of a spine is given.

These spicules doubtless belong to genus Geodia or some allied genus, as Tethya or Stellata. The body is somewhat globular and the spines rest squarely on bases more or less enlarged.

Figure 13. *Geodia? spini-curvata*, n. sp. Imperfect, elliptical, spheroidal, ornamented with what might with higher power lens prove to be minute blunt spines. Body has also long spines, smooth, slightly curved and irregularly arranged. Size: 0.096 mm. by 0.065 mm.; length of spine, 0.035 mm. Nothing similar to this has been found figured. From the slight curve of the spines I propose the specific name *spini-curvata*.

Figure 12. *Geodia? cretacea*, n. sp. Perfect. Much like Figure 13. Body ornate, smooth, and bearing numerous long and slightly curved

[1] Abh. K. Bayer. Akad. Wiss. d. Mün., XII., Bd. III., Taf. V. Figs. 27 and 30.
[2] Die Spongien des Adriatischen Meeres, p. 49, Taf. IV. Fig. 7a.

spines. The slight curve of the spines may be due to mechanical processes. Size: 0.1076 mm. by 0.092 mm.; length of spine, 0.035 mm. Nothing similar to this has been found described or figured. I propose the name *Geodia? cretacea.*

Figure 11. *Geodia? Austini,* n. sp. Imperfect. Breakage caused perhaps by mechanical movement or abrasion. Body spherical and smooth between the spines. Spines short, divided into minute barbs. Some of them have a double system of bifurcation. Size: 0.069 mm. from tip to tip; length of spine, 0.0153 mm. Not found figured. I propose the name *Geodia? Austini.*

Figure 14. *Geodia? irregularis,* n. sp. Spicule perfect. Body globular and smooth between the long spines. Spines are easily seen to be hollow tubes, variously terminated, but principally by short lateral projections near the end. Size: 0.1003 mm. by 0.088 mm.; length of spine, 0.0269 mm. Only one of this variety was found in the slides examined. I propose the name *Geodia? irregularis.*

Figure 15. *Geodia? tripunctata,* n. sp. Outline perfect. Body pear-shaped, smooth and hollow. Spines irregularly placed on body, slightly tapering and terminating in three slender barbs. Size: 0.073 mm. by 0.061 mm.; length of spine, 0.0236 mm. This was not found figured. I propose the name *Geodia? tripunctata.*

Figure 16. Hymeraphia? sp. Outline perfect. Body globular and ornate. Spines short and probably divided at end. This probably belongs to family Geodites, but the genus and species cannot be determined. I have thought it may be some form of genus Hymeraphia, recent species of which have been figured by Carter.[1]

Figure 17. Chondrilla? sp. Imperfect? Body globular, slightly elongated and ornate. Spines, some of which are removed from upper surface, are blunt but massive. Size: 0.053 mm. by 0.05 mm.; length of spine, 0.0076 mm. This is similar to a recent form *Chondrilla saccaformis,* figured by Carter,[2] and is provisionally referred to that genus.

Figure 18. *Geodia? Texana,* n. sp. Apparently bilobate. Body spherical and ornamented with short spines thickly set in surface of body. Longer spines irregularly arranged on surface, with spreading base tapering rapidly to a sharp point. Size: 0.076 mm. by 0.073 mm.; length of spine, 0.015 mm. Nothing similar to this has been found figured, yet it probably belongs to Geodia or allied genera. I propose the name *Geodia? Texana.* The specimen is one of rare beauty.

[1] Ann. Mag Nat. Hist., Ser. 5, 1879, Vol. III. Plate XXVI.

[2] Ibid., Vol. III., p. 299, Plate XXVI. Fig. 12.

Figure 19. Hymeraphia ? sp. Outline perfect. Body egg-shaped, and saccular. Spines irregularly arranged on body, short and perhaps divided at tip. Size: 0.042 mm. by 0.037 mm.; length of spine, 0.0057 mm. Somewhat similar forms are figured by Carter as belonging to the recent genus Hymeraphia.[1] It is therefore placed provisionally in this genus.

Figure 20. *Geodia? spinipansata*, n. sp. Outline perfect. Body egg-shaped and ornamented in a most peculiar way. The significance of the two apparent openings on top is not understood. Spines irregular in length and size, and variously divided at the terminations. Size: diameter, 0.092 mm.; average length of spine, 0.0307 mm. This peculiar form was not found figured, but from its spiny form I placed it with *Geodia*, and suggest the specific name *spinipansata.*

Figure 21. *Geodia? Hilli*, n. sp. Spicule perfect. Body elongated and smooth between bases of spines. Spines few and irregularly placed, spreading at base, tapering rapidly at first, then more slowly to the top from which extend three to five short barbs. The hollow tube may be seen the whole length of the spine. Size: 0.0938 mm. by 0.0884 mm.; length of spine, 0.0307 mm. This species is one of transcendent beauty. Nothing similar has been found figured. It perhaps belongs to some genus allied to *Geodia*, and I propose the specific name *Hilli.*

Figures 24, 25, 26, and 30 are very small globo-stellates covered thickly with small straight short spines. They vary in size from 0.023 mm. by 0.021 mm. to 0.028 mm. by 0.015 mm. Similar figures have been figured by Carter,[2] in describing the recent form *Hymeraphia spiniglobata.*

Figure 27. Small, circular, flat silicious disks with a smooth surface and often a dark somewhat irregularly shaped mass in or near the centre. Some of these having a dark spot in centre appear to have been replaced by amorphous silica, and the dark spot may be a collection of organic residue, though Sollas found that a dark spot in the middle of a recent sponge spicule was an air bubble. This form is very common, and often a hundred or more are found piled upon each other like piles of coin. Some of them are solid, but the greater number have a ring around the centre, or a black spot filling the centre. They also vary greatly in size; the ones figured are an average; diameter, 0.05 mm.

Figure 28. Dermal spicules? Rhomboidal and apparently flat in shape. Surfaces often pitted. Average size, 0.021 mm. by 0.0307 mm. Not found figured.

[1] Ann. Mag. Nat. Hist., Ser. 5, 1879, Vol. III. Plate XXVI.

[2] Ibid., Vol. III., p. 301, Pl. XXVI. Figs. 5-16.

Figure 29. Geodia sp. A globate spicule, perfect. Body ornate, with minute spines. Size 0.035 mm. by 0.0321 mm. It is somewhat similar to globates figured by Dr. Hinde from Upper and Lower Greensand,[1] but is much smaller and not ornamented.

Figure 31. A siliceous globule similar in shape and surface to Figure 27, but larger. The surface seems to be composed of or covered with dark brown granules and a large irregular dark spot in the centre. The nature of this spot is unknown, but it has every appearance of peroxide of iron. As has been said it is a common phenomenon, and is sometimes round, but is more often irregular. The color as well as the irregular form would, it seems to me, prevent it from being an air bubble similar to the one figured by Sollas.[2] The dark brown granules on the outside are supposed to be grains of iron ore, but their formation as well as their nature is not understood.

Figure 32. Geodia? sp. Spicule perfect. Pyramidal in form, with one branch of base shorter than others and the shaft much longer. The replacement is by amorphous silica, but axial canal not preserved. The surface somewhat pitted, showing irregularity of replacement. Length of shaft, 0.333 mm.; width of shaft, 0.0269 mm; spread of arms, 0.173 mm. This belongs to some form of Geodia altogether much smaller than any I have found described. There are larger ones in the Texas flint, but they were not so perfect in form. No clearly defined specimens of anchorate spicules were found, although some were found that indicated pretty clearly through their mutilated parts that they belonged to the family Anchorinidæ. From these imperfect specimens, and also from the fact that the family of Geodidæ is so abundantly represented, I conclude it reasonable to suppose that the other family of Tetractinellidæ was also present to a limited degree at least.

LITHISTIDÆ, Oscar Schmidt.

The order of Lithistid sponges is almost entirely absent from the Texas flints, so far as I can definitely determine, with the exception of a flesh spicule, Figure 23, which is doubtfully called a Lithistid. In addition to this there are a number of areas of chalcedonic silica that have an indefinite trace of an outline similar to a Lithistid, but, since the chalcedony has a concentric structure, nothing definite was made out. One was found incomplete as to terminations, and hence not

1 Phil. Trans. R. S., Part II., 1885, p. 441, Pl. XLIII, Fig. 2c.

2 Ann. Mag. Nat. Hist., Ser. 4, 1877, Vol. XX. p. 292.

figured here. It is very small, and the doubt cast by its size, together with its incomplete form, led me to discard it after drawing it. It is similar in form to one figured by Hinde.[1] Traces also similar to one in the Annals and Magazine of Natural History[2] are common in the slides. There is but little doubt, therefore, that Lithistid sponges were present in the flint forming ocean bottom, although through the accidents of nodule formation they have all been destroyed. The following spicule I have provisionally placed with the Lithistids.

Figure 23. Irregular in outline. Transparent, yellowish, with smooth surface. Has the appearance of colloidal silica slightly colored. Length, 0.173 mm.; width, 0.09 mm. Similar spicules are figured by Dr. Hinde.[3]

HEXACTINELLIDÆ, Oscar Schmidt.

In this order the siliceous skeleton consists of elements founded almost without exception upon three axes crossing each other at right angles. This group is poorly represented in the Texas flint nodules, though Figures 33 and 34 are common.

Figure 33. Spicule imperfect. Form quadradiate with arms extending almost the same size throughout in *a*, and tapering slightly in *b*. Axial canal faintly shown in *b*, and lower arm turned slightly upward, making an angle with the other. Length of arms varies from 0.266 mm. in *a* to 0.466 mm. in *b*. They may have been considerably longer, however, when perfect. Similar spicules are figured by Hinde from Greensand of Halsmere and Blackdown,[4] and given the name Stauractinella. Professor Zittel figures one also nearer the size of one in the Texas flint.[5] It is perhaps a little smaller, but more nearly perfect.

Figure 34. Part of framework of Stauractinella? The four arms are slender, and of uniform size throughout the whole length; one arm is represented by a small projection from the joint, and another arm is absent? The replacement is by peroxide of iron, which appears in bead-like balls mixed with amorphous silica. Length of arms, 0.186 mm. to 0.266 mm. This is similar to one mentioned by Dr. Hinde.[6]

Figure 35. Mesh spicule? The size of this spicule, as well as its

[1] Fossil Sponges in Upper Chalk, p. 5, Fig. 4.

[2] Ser. 5, 1878, Vol. II., Plate VII. Fig. 7.

[3] Fossil Sponges in Upper Chalk.

[4] Phil. Trans. R. S., Part II., 1885, p. 446, Pl. LXVI. Fig. 10a.

[5] Abh. d. II. cl. d. K. Ak. d. Wiss., XII., Bd. III., Abth., Taf. V. Fig. 53.

[6] Phil. Trans. R. S., Part II., 1885, p. 446, Pl. LXVI. Figs. 10 and 10a.

imperfect state, has led me to doubt whether it can be referred to this position. Its color and appearance in polarized light indicate that it is colloidal silica, and its arms seem to cross at right angles. In form it may be considered somewhat similar to genus Leptophragma, Zitt., several forms of which are figured by Hinde.[1] The size of the entire figure is 0.0615 mm. by 0.046 mm. It is placed here doubtfully, therefore, because of similarity of form, but as these sponges may be supposed to have died in all stages of growth, it is reasonable to suppose that the size would be subject to much variation. The one figured was the only one found.

Formation of the Nodules.

The question of the formation of the flint nodules has received considerable attention in the past, and the problem may not yet be altogether solved. Although I do not expect to throw any light on the subject by this brief study, yet I hope to use the observations I have made as illustrations in the discussion of the conclusions of others. In order to get the question fairly before us, I quote from Dr. Wallich: "The stratification of the flints is due to the fact that nearly the whole of the silex derived from the sponges on the one hand, and the continual subsidence of minute dead siliceous organisms on the other, is retained in the general protoplasmic layer which I have shown maintains its position on the immediate surface of the calcareous deposit and gradually dissolves the silex. This layer in virtue of its inferior specific gravity rises with every increase in the thickness of the deposit, until at last the supersaturation of the protoplasmic masses with silex takes place, and the first step towards the consolidation of the flint is accomplished, — the continuity of sponge life and of the various other forms which tenant the calcareous bottom being secured through the oozy spaces which separate the sponge beds, and thus admit of both adult and larval forms having free access to the overlying stratum of water." [2]

While this refers primarily to the formation of strata of flint rather than nodules, yet the solution and distribution of the solution of the siliceous organisms must be the same in both cases. The process of segregation by which the solution is concentrated into nodules, taking every vestige of spicule out of the surrounding chalk, needs additional explanation. On this subject I quote from Professor Sollas.[3] In this, he

[1] Fossil Sponges from Upper Chalk, p. 65, Pl. V. Figs. 17–19.

[2] Quarterly Jour. Geol. Soc., 1880, Vol. XXXVI. p. 88.

[3] Ann. Mag. Nat Hist., Ser. 5, 1880, Vol. VI. pp. 441, 442.

takes the position that flints are formed by continuous growth of sponges *in situ* for successive generations. But while he thinks this is true, he accounts for the absence of the once existing flesh spicules by supposing that they have all been dissolved. On page 459 of the same paper he accounts for the peculiar forms of nodules by saying that they indicate the irregular distribution of siliceous solutions about an irregular bed of sponge spicules, at the time in which they replaced the surrounding chalk and deposited silica in its interstices. The views of these eminent men are doubtless the results of profound study and extensive observation, and are entitled to the most careful consideration; therefore, before I comment on them, I desire again to remind the reader that my observations are limited to a few nodules, and that I shall discuss the formation of these few rather than the formation of flint nodules in general.

It will be remembered that, in giving the method of preparation of the flints for study, I stated that sections were cut through the centre and also near the surface to find if possible any difference in the condition of preservation of the spicules. The result of the study showed that, while there was little difference in the preservation of the spicules in the body of the nodule, yet it appeared that near the surface there was more crushing and mechanical wear than further in the interior. Especially was this true of the Monactinellid, Figure 7, which was more abundant near the surface and was never found perfect. It should be stated, however, that the mechanical crushing differed considerably in the different specimens, and one showed complete obliteration of spicular structure. In the sponge spicules studied by Carter, Sollas, and Hinde, all of which had been subjected to mechanical movement, the smaller spicules had all been destroyed. Carter says that he did not find minute stellates, or spines, or tubercles on the large spicules in the Haldon deposit.[1] Sollas says that the once existing spicules are absent because they have been dissolved.[2] Hinde says that flesh spicules are rarely met with in the fossil state.[3]

Texas flint nodules, however, show a scarcity of zone spicules and a great number of flesh and dermal spicules. Moreover, these minute stellates, which are covered with exceedingly delicate spines, are perfectly preserved even to the most minute barb on a spine not exceeding 0.0037 mm. in length. It was noticed also that each slide had a num-

[1] Ann. Mag. Nat. Hist., 1871, Vol. VII. p. 118.

[2] Ibid., Ser. 5, 1880, Vol. VI. p. 442.

[3] Fossil Sponges of the British Museum, Introduction.

ber of spicules peculiar to itself that were rarely or not at all found in the other nodules. The Monactinellids, especially Figure 7, were found in nearly all the slides, and I think Figure 7 was found in every nodule examined. Knowing the destructive effects that even a slight friction of these among one another would have on the delicate barbs, we must conclude, it would seem, that these spicules have never been moved, but have been developed on the spot where they are found. Some of these globo-stellates that are broken may have been carried from surrounding sponge beds and broken up on the road, but, as these occupy the outside chiefly, it is easily seen that such movement and consequent breakage would be a natural result. It therefore seems to me that this study is a confirmation of the view taken by Professor Sollas that the flints result from the continuous growth of sponges *in situ*, and that the presence of the minute spicules so perfectly preserved, and which he did not find, furnish the strongest proof. I must dissent, however, from his other conclusion, that the nodules are replacements of chalk by siliceous solutions deposited in the interstices.

In the Texas flints there are comparatively few of the chalk-forming organisms found fossil, and these are so isolated that they seem to have no connection at all with one another. It is reasonable to suppose that they may have fallen into the framework of the sponge and sunk down into the siliceous mass on the death and decay of the sponge body. In one nodule there were four concentric rings of chalk followed by as many of silica on the outside of the nodule. The chalky material was silicified but not replaced, and it is but reasonable to suppose that such would have occurred within the nodule had the nodule been formed by the replacement of the chalk as Professor Sollas proposes for the nodules of the English flint. Therefore, in consideration of the above points, I have thought it allowable to suggest that each nodule represents a separate sponge bed, in which many generations of sponges have lived and died in all stages of development. On the death of any certain part, the spicules fell away, many of them down below into the mass at the bottom. Here the process of solution went on continually, and nearly all the spicules were dissolved and few left in the dissolved mass. Why so many of the dermal spicules are left and the zone spicules nearly all dissolved is hard to account for, and I have no explanation to suggest. Many of the spicules would doubtless fall outside of the growing mass, and these might be dissolved according to the method suggested by Dr. Wallich elsewhere quoted, and by movement through the water settle around the masses already dissolved, and thus form the concentric rings above

referred to, and also account for the broken condition of the peripheral spicules. This would also account for the fact that each nodule had a prevailing number of spicules peculiar to itself, while a few were common to all. The peculiar form and size of the nodules may also receive an explanation here. If the sponge takes root in the ooze of the ocean bottom and becomes firmly embedded, there will be at its bottom a considerable cavity where the bottom part dies. We have no means of knowing how rapidly the oozes accumulate, but if they accumulate as rapidly as the dissolved silica accumulates, then it would seem that the ooze might enclose a pocket of the silica, having grown up around the base of the sponge. In this way, the flint nodule would grow as the sponge mass may have been expected to grow; namely, it would begin small, reach a maximum size, then decrease in size, and finally end in a point as it began. The shapes of the flints that I studied indicate that such a growth may have taken place. The consolidation of the silica into flint and the ooze into chalk may have taken place about the same time, but the condition of preservation of the spicules indicates that there was very little pressure applied to the spicule before the consolidation into masses so hard that pressure would not change the structure of embedded fossils.

Mr. John Murray[1] says that in the deep sea at present many of the Foraminifera gather around them spicules of sponges as shells. The Pilulina, etc., are covered with tests entirely constructed of cemented sponge spicules, and suggest that this may be the beginning of a concretion of flint or flint nodule. This, as is true also of several other suppositions, is a plausible theory, but it seems that the small delicate spicules of the Texas flint nodule could hardly have been preserved so perfectly where the amount of movement necessitated by such a process had taken place.

Hence, while recognizing that my conclusion as to the process of formation of the Texas flint nodules leaves several points unexplained, and although I realize full well its incompleteness, yet I think it accounts for more of the facts than any hypothesis I have seen.

Summary.

The variety and mixture of the different kinds of sponges named in the preceding pages make it difficult to tell anything about the depth of the ancient cretaceous sea. Geodia, which is so fully represented,

[1] Report of H. M. S. "Challenger," Volume on Deep-Sea Deposits, p. 263.

and Stauractinella, are both deep-sea sponges, but are also found in shallow water. Figures 24, 25, 26, 30, and 31 are similar to deep-sea recent forms figured by Carter, while the Monactinellid sponges are shallow water forms. Dr. Hinde concludes that the sponges in the Horseford flint "do not show conclusively the depth of the water of the deposition."[1]

In the Challenger Reports, Volume on Deep-Sea Deposits, Mr. Murray takes the position that the chalk was not the same as the present globigerina ooze, because the species of Foraminifera in the chalk are principally shallow water forms. However, the appearance of the nodules so seldom in the cretaceous formations seems to indicate a very peculiar combination of circumstances which existed but once in a great cycle of changes. From its proximity to known shore lines, we may judge that this formation was not in the deepest sea, yet from the forms of animal life preserved in it we may conclude that it was beyond the continental shelf, in water deep enough to secure the conditions necessary for long periods of time.

[1] Fossil Sponge Spicules of the Upper Chalk, p. 76.

EXPLANATION OF THE PLATE.

Fig. 1. Monactinellid. Axinella? sp. Replaced by chalcedonic silica. × 80 diameters.

Fig. 2. Monactinellid. Axinella? sp. Replaced by chalcedonic silica. × 20 diameters.

Figs. 3, 4, 10, and 36. Monactinellid. Reniera? sp. Bodies replaced by amorphous silica, canal by chalcedonic silica. × 80 diameters.

Fig. 5. Monactinellid, acuate spicule. Replaced by chalcedonic silica. × 80 diameters.

Fig. 6. Monactinellid. Spicules covered with minute projections, canal enlarged. × 80 diameters.

Fig. 7. Monactinellid, dark outer covering, probably iron ore. × 80 diameters.

Fig. 8. Monactinellid. Replaced by amorphous silica. × 80 diameters.

Fig. 9. Monactinellid. Esperia? sp. In amorphous silica. × 80 diameters.

Fig. 11. Tetractinellid. *Geodia? Austini*, n. sp. In colloidal silica. × 275 diameters.

Fig. 12. Tetractinellid. *Geodia? cretacea*, n. sp. In colloidal silica? × 275 diameters.

Fig. 13. Tetractinellid. *Geodia? spini-curvata*, n. sp. In colloidal silica? × 275 diameters.

Fig. 14. Tetractinellid. *Geodia? irregularis*. In colloidal silica? × 275 diameters.

Fig. 15. Tetractinellid. *Geodia? tripunctata*, n. sp. In colloidal silica. × 275 diameters.

Fig. 16. Tetractinellid. Hymeraphia? sp. × 275 diameters.

Fig. 17. Tetractinellid. Chondrilla? sp. In colloidal silica? × 275 diameters.

Fig. 18. Tetractinellid. *Geodia? Texana*, n. sp. In colloidal silica. × 275 diameters.

Fig. 19. Tetractinellid. Hymeraphia? sp. In colloidal silica? × 275 diameters.

Fig. 20. Tetractinellid. *Geodia? spini-pansata*, n. sp. In colloidal silica? × 275 diameters.

Fig. 21. Tetractinellid. *Geodia? Hilli*, n. sp. In colloidal silica? × 275 diameters.

Fig. 22. Tetractinellid. *Geodia tripunctata?* n. sp. Fragments resulting from solution. × 275 diameters.

Fig. 23. Lithistid? Flesh spicule. × 275 diameters.

Figs. 24, 25. Tetractinellids. Hymeraphia? sp. Globostellates in colloidal silica? × 275 diameters.

Fig. 26. Tetractinellid. Hymeraphia ? Globo-stellate in colloidal silica ? *a* × 275, *b* × 550 diameters.

Fig. 27. Tetractinellid. Geodia ? sp. Dermal spicule. × 275 diameters.

Fig. 29. Tetractinellid. Geodia ? sp. Siliceous globate, spicule ornate. × 275 diameters.

Fig. 30. Tetractinellid. Globo-stellate of dermal layer. In colloidal silica ? × 275 diameters.

Fig. 31. Geodia ? A siliceous globule, body amorphous silica covered with granules of iron peroxide. × 275 diameters.

Fig. 32. Geodia ? Pyramidal or zone spicule replaced by amorphous silica. × 80 diameters.

Fig. 33. Hexactinellid. Stauractinella ? sp. Quadriate spicule in amorphous silica. × 80 diameters.

Fig. 34. Hexactinellid. Stauractinella ? sp. Replaced by peroxide of iron and amorphous silica. × 80 diameters.

Fig. 35. Framework of a Hexactinellid ? Mesh spicule in colloidal silica. × 275 diameters.

Fig. 36. Monactinellid. Reniera ? sp. Found in outer margin of nodule. Replaced by amorphous silica. × 80 diameters.

These drawings were all made with the camera lucida by Mr. J. H. Emerton of Boston.

MERRILL – TEXAS FLINT.

J.H.E. del

B Meisel, photo.lith

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(Geological Series. Vol. III.)

THE ELEVATED REEF OF FLORIDA.

By ALEXANDER AGASSIZ.

WITH NOTES ON THE GEOLOGY OF SOUTHERN FLORIDA.

By Leon S. Griswold.

With Twenty-Six Plates.

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No. 2 — *The Florida Elevated Reef.* By ALEXANDER AGASSIZ. *With Notes on the Geology of Southern Florida.* By LEON S. GRISWOLD.

The Florida Elevated Reef. By ALEXANDER AGASSIZ.
(Plates I. to XVII.)

I WAS anxious to examine again the Florida reefs in the light of the experience gained by my visit to the Bahamas and Bermudas; and as was anticipated, my ideas of the mode of formation of the Keys have been materially changed, and I no longer consider the Marquesas as a true atoll.[1] After having seen at the Bermudas the mode of formation of the sounds, I have become satisfied that the Marquesas are a sound. But the Marquesas Sound, as well as other Florida sounds, does not, I think, owe its origin to subsidence, but merely to the mechanical and solvent action of the sea. It is interesting to trace on the large scale charts of the Coast Survey (Nos. 167–169) the mode of formation of Key Biscayne Bay, composed of two sounds, followed by Barnes Sound, and finally to the westward, by the Bay of Florida, itself only a series of disconnected sounds indicated by isolated keys and bars. The same disintegration is going on at the Pine Islands, Key West, Boca Chica, Boca Grande, Ballast Key, and is especially well seen in Key Largo and the Marquesas, to the west of the principal line of keys, being a remarkably well preserved sound of an elliptical shape.

To my great surprise I found that Lower Matecumbe was edged by an elevated reef about two feet above high-water mark, and this elevated reef I was able to trace all along the shores of the keys to the east of Indian Key as far as Soldier Key, off the central part of Key Biscayne Bay. I examined this elevated reef also at Indian Key where its highest point is eight feet above high-water mark, at several points on Key Largo, Old Rhodes, Elliott Key, and, as the most easterly point, Soldier Key. No trace of this elevated reef could be detected north

[1] See Note on the Florida Reef, by A. Agassiz. (Letter to J. D. Dana dated Tampa Bay, Florida, December 27, 1894. From the American Journal of Science, Vol. XLIX., February, 1895.

of Cape Florida, Key Biscayne being entirely covered by siliceous sands, just as the beaches of limestone sands cover great tracts of the keys lying to the westward and hide the underlying elevated reef, which crops out, however, on the outer line of keys, as at Sand Key. Shaler speaks of having traced this reef at Old Rhode's and having followed it to the Miami River as an elevated reef. I was quite surprised on examining a bluff about ten feet in height, extending eastward from Cocoanut Point toward the mouth of the Miami River, to find that it consisted of *æolian rocks* which have covered the elevated reef in many places. On the low shores these æolian rocks are honeycombed and pitted and might be readily mistaken for decomposed reef rocks; but they contain *no* corals. This looks as if the lower southern extremity of Florida, the Everglade tracts, was a huge shallow sink, or a series of more or less connected sinks, into which sand had been blown forming low dunes which have little by little been eroded, and which former observers had mistaken in some localities for reef rock. The material for these dunes coming from the now elevated reef or the beach rock at a time when it was either a fringing or a barrier reef along the former coast line of Florida, all of which, back of the reef, has little by little been eroded by the mechanical and solvent action of the sea, leaving on the mainland only an occasional outcrop of the elevated reef as observed by Professors L. Agassiz and Shaler. The outer line of reef has also been elevated. For I think Tuomey was right in looking upon the outcropping reef rock of Sand Key as an elevated reef, while Professor Agassiz mistook it, as well as the traces of the elevated reef he saw along some of the keys, for a recent reef consisting of beach rock into which large masses of corals had been thrown by hurricanes. But in this I now think both he and I were mistaken. It was, however, a natural view to take of the formation of that reef for one who was not familiar with the peculiar aspect of the elevated reefs of Cuba. From the Pine Keys and the islands to the west, and including the Marquesas, there is nothing exposed but beach rock (Plates I., V.), stratified at a slight angle seaward on the sea faces of these keys; and even that is only casually exposed, — the greater part of the southern beaches of those keys being covered by coralline and coral sand completely hiding the substratum (Plate II.). Behind and upon this beach rock, æolian rocks stretch northward and have formed the keys.

Since my visit the material for the determination of the thickness of the Florida coral reef has been obtained, and we have now accurate data obtained by boring.

Mr. Peter A. Williams, of Key West, was kind enough to have collected for me samples from the Artesian well bored at Key West in 1895. This well was carried to a depth of 2,000 feet. Samples were taken every twenty-five feet. The specimens I sent to Mr. E. O. Hovey for preliminary examination, and his report will follow this Bulletin. The most interesting result obtained is that the thickness of the coral reef formed since Pliocene times is probably about fifty feet.

Dr. Hovey places the upper limit of the Vicksburg beds at 700 feet from the surface, but he has been unable to determine the lower limits of the Miocene and Pliocene. As will be seen by his report, many of the samples indicate beach deposits, or deposits formed in comparatively shallow water. The Foraminifera are now under examination, and it is hoped that some light may be thrown on the subject from these results, as well as from the comparative examination of the borings of other Florida wells undertaken by the geologists of the United States Geological Survey. I have also added to Mr. Hovey's report the chemical analysis of the samples kindly made for me by direction of the Hon. C. D. Walcott, Director of the United States Geological Survey.

On the smaller island to the southwest of Bahia Honda there is a fine exposure of a portion of the elevated reef. The rock is full of heads of Colpophyllia, Mæandrina, and Orbicella. The highest point of the elevated reef is not more than a couple of feet above high-water mark. The lee side of the small island is in part covered with æolian sand derived from the breaking up of the weather side of the elevated reef patch. In addition to the æolian sand which covers the eastern part of this small island we find sand composed of coralline and broken shells and coral material, forming at some points a dike fully two feet high, which has been thrown up by the sea. This small island is interesting as showing how the underlying reef rock of the larger keys has gradually been covered over with æolian sand blown from the disintegrated elevated reef itself, or how the sand has been piled up on the top of the reef to leeward, and formed bars or flats which have gradually increased until they have built up a great part of the land of some of the prominent keys of the western extension of the Florida Keys. Or this sand may have taken the place of the land eroded from the mainland by the action of the sea after the elevation of the reef which edged the former shore line of Southern Florida took place.

The sand on Bahia Honda itself consists of the same material as that described above, but it is more finely comminuted. At this point the elevated reef must have been of considerable width, for its northern

edge crops out on the north side of Bahia Honda. The elevated reef at Bahia Honda is the most western point to which portions of the inner elevated reef have been traced. Undoubtedly there are patches of it still left in from two to three feet of water off the line of keys extending westward from Big Pine Key as far as Key West, and perhaps off the keys to the westward of that island. But west of Bahia Honda the inner elevated reef has been eroded, and no part of it reaches the surface. The material derived from this erosion having gone in great part as æolian sand to build up the line of keys to the west of Bahia Honda.

At Boot Key we found a patch of the elevated reef about two feet above high-water mark, honeycombed, pitted, and full of heads of Mæandrina, Orbicella, and Colpophyllia, as well as of massive conchs. A coral sand beach covers the elevated reef to the eastward, but it crops out again farther east, as well as westward. In these patches occurred the same species of corals. The borders of the elevated reef were covered with masses of tests of Echini, of fragments of Gorgonians, of sponges, and of blocks made up of bivalves which had become cemented together. This material, if overwhelmed with calcareous sand and cemented and hardened, would form a magnificent bed of fossils. The upper parts of the beaches flanking the patch of elevated reef are covered with masses of Porites and of bivalves, and as we approach low-water mark this material is ground to fine powder.

The elevated reef at Indian Key (Plates VI., VII.) rises about six feet above high-water mark. It is exposed along the greater part of the outer edge of the island. Towards the interior the island is covered with low vegetation, and the surface of the higher parts of the elevated reef has been changed to a hard ringing limestone. The outer edge of the reef is pitted and honeycombed, and full of small pot-holes; the sea is gradually encroaching upon the sea face of the reef, and eating slowly into the island. The corals observed are mainly species of Orbicella, Colpophyllia, and Mæandrina.

At the eastern extremity of Lower Matecumbe the elevated reef, which is hidden by coral sand for the greater length of the island, has been exposed by the hurricane of September, 1894. During that hurricane about sixty feet in width of the coral sand beach was carried away, leaving the underlying elevated coral reef fully exposed, but not more than twelve to fifteen inches above high-water mark, very much lower than at Indian Key.

We examined the shores of Key Largo at two points, one near the western extremity of Card's Sound, the other about half-way between

Rodriguez and Tavernier Keys. At these points the elevated reef did not rise more than about twelve inches above high-water mark, and presented the same pitted and honeycombed appearance which characterized the elevated reef elsewhere. The reef rock was full of pot-holes, and we recognized as forming a part of the elevated reef blocks of the same species of Orbicella, Mæandrina, Astræa, and Colpophyllia characterizing the elevated reef elsewhere. The elevated reef shelves very gradually to the eastward, and at a distance of nearly half a mile from the shore we could recognize it below water.

In order to determine, if possible, the width of the elevated reef, a section was made across Key Largo extending from the low shore line of the elevated reef to the east of Sound Point, at right angles to the trend of the coast. Specimens were collected every 500 feet, and it was found that the elevated reef extended about 3,000 feet from the shore. Beyond that point the rocks collected seemed to indicate an æolian formation blown into a shallow sink behind the elevated reef, much as we observed it on some of the other keys, as at Key West, Boca Chica, the Marquesas, and others, where the elevated reef has either been eroded, or has been completely hidden by the sand thrown upon and over its surface from the shore line and adjacent flats.

This would seem to indicate a probable width of the Florida reef at that point of at least nine miles from the outer reef patches, a width of reef patches without parallel in any other coral reef district of the West Indies.

The elevated reef crops out again near the eastern extremity of Elliott Key (Plate VIII.). Its highest point is from five to six feet above high-water mark. The part of the island where we landed is interesting, as showing next to the elevated reef a small beach of coral sand overlappin the reef (Plate IV.). Judging from the aspect of the keys as we steamed along, the reef alternately crops out or is covered by coral sand, forming beaches in low places, or banks alternating with clusters of mangroves and strips of land behind the elevated reef, separating the inner sounds from the waters bathing the southern shores of the keys.

The elevated reef is pitted, honeycombed, and full of pot-holes. From what we have seen thus far the impression is produced that the outer line of keys were once a part of one extended reef or patches of reef, which formed a fringing or an edging reef off the southern edge of the peninsula of Florida, and that the reef was subsequently elevated, and the land thus raised eroded by the combined action of the rain and of the sea. The process must have been very similar to that which gave

to the north shore of Cuba, between Cardenas and Nuevitas, its present configuration. Only in the case of Florida a greater stretch of the land to the rear of the keys was changed into flats and bars than is the case on the Cuban coast. (See Pl. XIII. Figs. 1–4, Bull. Mus. Comp. Zoöl., XXVI. No. 1.)

The corals of the elevated reef on Elliott Key belong to the same species as those occurring on the patches of the elevated reef of Indian Key, of Lower Matecumbe, and of Key Largo. They are mainly species of Orbicella, Astræa, Mæandrina, and Colpophyllia. On Elliott Key many large patches of the reef rock consisted entirely of the shells of conchs.

The Ship Channel, separating the outer line of reef patches from the main line of keys, may represent a sink of greater extension, which the currents have swept clean, and gradually deepened after it became freely connected with the sea at many points and along wide stretches. Here and there only do we find in the channel reef patches, the remnant of larger patches of the former elevated reef, upon which corals are now growing. Such patches are the Middle Ground, the Hen and Chickens, Washerwoman East and West Shoals, the North Shoals, the Triangles, and the innumerable bars and heads which fill the channel east of Carysfort Reef back of Ajax Reef, and stretch towards Fowey Rocks, where the outer reef almost joins the inner line of keys.

The seaward extension of the elevated reef and reef flats and patches can be traced along the outer line of the reef from Sand Key to the eastward, as well as along the line of heads which stud the Ship Channel.

The Hen and Chickens heads are formed by corals growing upon patches of the older elevated reef, which can be seen rising irregularly from various depths. The faces of these patches all show the effect of the action of the sea, and are cavernous and deeply eroded. We found that the Fowey Rocks, as well as the ledges near them, showed the same structure; but both at the Fowey Rocks and at Alligator Reef Madrepora palmata plays an important part in the growth of the corals covering the heads, while in the Hawks Channel the heads are mainly Gorgonians, Orbicellas, Mæandrinas, Astræans, and coralline Algæ, with comparatively few Millepores. In the Florida district the slight development of Millepores is in marked contrast with their abundance in the Bahamas and Bermudas. On Plantation Key the elevated reef rises to a height of nearly fifteen feet.

An examination of the heads of the Washerwoman Shoals shows very plainly the old decomposed reef rock forming the base upon which the new heads of the existing reef have grown. The heads are surrounded

by a coralline bottom, on which are found scattered specimens of Mæandrina, coarse fragments of Astræans, Echini, and corallines such as Udotea and Halimeda mainly. The bottom is of a similar character half-way between Washerwoman Buoy and Boca Chica. In the middle of the main channel, all along the reef, the same coralline sand is usually found thickly packed with Udotea and Halimeda.

At Sand Key we found the reef rock elevated fully two feet above high-water mark. The parts of the former elevated reef form a series of pinnacles, on the sea face of which corals are now growing. The central part of the key is covered by a mass of fragments of corals of all sizes, finely ground with sand, and thrown up to a height of about eight feet. Much of the elevated reef is often uncovered by hurricanes, as was the case during the hurricane of September, 1894, when the sea washed over the whole island. The elevated reef of which Sand Key forms a part was evidently not raised to as great a height as the ancient reef farther north. At Sand Key it is not difficult to distinguish between the elevated reef and the living reef, the line of demarcation is quite sharp.

At Sombrero Key we could not separate the elevated reef from its coating of recent corals, especially since a good deal of coral had evidently been killed by exposure to the air. But off Sombrero Light we found old elevated reef rock honeycombed and pitted, and surmounted by growing heads of coral, just as we had observed them at the Hen and Chickens.

An examination of the Chart (Plate XVI.) shows that the shores of the islands which stand opposite great gaps in the reef are all covered with coral sand, as, for instance, in the great stretch between American Shoal and Alligator Reef, where the shores are exposed to the sweep of the sea, which throws up at times great masses of coral and coralline sand, covering the elevated reef. This undoubtedly extended in a more or less continuous stretch all the way along the former shore line of the southern face of Florida. It has, however, at some points, been little by little covered by the sand thrown up from the stretches exposed to the sea, and at others the wearing action of the sea has broken through the reef and formed the shallow passages which now separate adjoining islands.

East of Alligator Reef the main line of keys is far more sheltered, a nearly continuous reef stretching from that point as far as Fowey Rocks, there being only an occasional gap in the broad reef. This stretch of the reef is in striking contrast to the narrow and insignificant

reef north of Fowey Rocks, to the disconnected patches west of Alligator Reef as far as Sand Key, and to the open line of keys stretching west of Key West to the Marquesas.

The outer reefs are growing upon old reef rock ledges, now elevated. They flourish on the ruins of the old reef, which itself must be underlain by the shore extension of the formation known as the Pourtalès Plateau. This near the outer edge of the reef is covered with sand and reef material, so that its in-shore limit cannot be determined except by borings. According to Mr. Hovey's determination, the thickness of the elevated reef at Key West is probably not greater than fifty feet.

It now becomes an interesting question to trace on the mainland the inner limits of the elevated reef. What we know of the subject we owe to the observations of Professor L. Agassiz and Professor Shaler, but they only penetrated a comparatively short distance inland from the shore of Key Biscayne. To obtain additional information on this point, Mr. L. S. Griswold made, at my request, an expedition into the interior, with the intention of reaching Long Key on the edge of the Everglades, and of ascertaining the nature of the rock which is said to crop to the surface at that part of the Everglades.

Mr. Griswold succeeded in reaching a point close to the so called Long Key,[1] and gives a most interesting account of the appearance of the southern part of the Everglades. He penetrated inland a distance of about twenty-three miles. He ran three lines into the interior, one from Black Point Creek, at the western extremity of Key Biscayne Bay, a second line following the Miami River and branching off in a westerly direction towards Long Key, and a third line following the course of New River. He also explored Florida Bay as far as Cape Sable to the east, and extended his observations to the north along the east coast of Florida, examining such localities as Boca Ratones, Lake Worth, Linton, and Cape Canaveral.

Mr. Griswold traced the extension of the æolian limestones more or less modified to the most distant point he reached, though he considers the oölitic rocks he collected as having been formed under water, an opinion with which I cannot agree. The specimens he has collected are all, in my opinion, only modified æolian rocks, such as are found anywhere in the Bahamas and Bermudas. The very oölitic bluff to the westward of Miami River, — a photograph of which I owe to him (Plate XIX.), — which in his opinion has been deposited in water, is a most characteristic æolian rock, showing in its stratification the

[1] See his route, Plate XVII.

peculiar knife-edge layers, running at all angles, so striking in such formations.

Mr. Griswold also suggests that oölitic rocks are formed in the bottom of the sounds. The oölitic sand and fragments of oölitic rock covering the bottom of the Florida sounds is derived from the disintegration of the æolian rock and of the reef rock which constitute the substratum and the highest parts of the keys, and from their extension inland (perhaps twenty to thirty miles) along the southern extremity of Florida from New River to Cape Sable. This whole territory being, according to the determinations of Dr. E. O. Hovey, based upon an examination of the samples from the Key West Artesian well, underlain at a depth of about fifty feet, or less inland, by Pliocene rocks and at a depth of 700 feet by Eocene strata.

Professor L. Agassiz, in his Report on the Florida reefs,[1] mentions the existence of coral reefs in the interior of the mainland at a distance of about five miles from the mouth of the Miami River. Owing to the conclusions which he drew from the existence of this reef regarding the probable mode of formation of a great part of the southern extremity of Florida, his premises regarding the reef have been questioned. Professor Shaler has described in detail a portion of the elevated reef which he found at some distance from the shore line. This leaves no doubt of the existence of an elevated coral reef of very great width, or of a succession of patches and flats covered by corals. The conclusions drawn from the presence of this elevated reef by Professor Agassiz regarding the structure of the greater part of the peninsula of Florida are thus seen to apply, though in a very modified sense, to a comparatively narrow strip only of its southern extremity. Undoubtedly some of the rotten honeycombed and pitted rocks which are observed all along the shore of the mainland from Cocoanut Grove to the mouth of the Miami River are composed of æolian rock, the rock on the shore line being the remnant of an extended series of low æolian hills of which the traces can be found here and there in the stretch of shore mentioned. In one locality a bluff of æolian rock fully twelve feet high (Plate XIX.) is still standing, and testifies to the existence of an extended beach of coral sand derived from the wide stretches of now elevated coral reef which undoubtedly flanked at one time the southern shore line of the peninsula of Florida. Parts of this broad reef belt are still visible to the southward as far as Bahia Honda and Sand Key, and it can be traced uninterruptedly, except where covered by sand

[1] U. S. Coast Survey Report for 1851; Mem. Mus. Comp. Zoöl., Vol. VII. No. 1.

thrown up by the sea, all the way from that point to Soldier Key, which is the last exposure of the southern face of the patches visible on the line of the keys. While their northern face, traced by Professor Shaler on the mainland back of Cocoanut Grove to a height of nearly twenty feet, is separated from it by the whole width of Key Biscayne Bay, which has washed away all traces of the connecting reefs and of the smaller sinks separating its patches and bars.

The most prominent points at which the elevated reef crops out are Sand Key, Bahia Honda, Indian Key, Key Largo, Lower Matecumbe, Old Rhodes, Elliott, Ragged, and Soldier Keys. That the elevated reef must have been greatly eroded Shaler has already shown in his section from Key Biscayne Bay, extending into the Everglade district. From what has been observed by Professors Agassiz, Shaler, and myself on the southern edge of the mainland, there are now found there great patches of æolian rocks filling intermediate sinks and alternating with patches of reef rock of greater or less extent, or perhaps covering the connecting coral ledge.

The well preserved condition of the elevated reef of the Florida Keys, as well as that of the northern shore of Cuba, would seem to be a strong argument in favor of the view taken by Shaler, that the elevation, or the series of elevations, which took place in Florida in the present geological period, must have been more or less paroxysmal in their nature.

Shaler adopts the view of the formation of the peninsula of Florida, as well as of the Bahama Bank, as due to a great fold, formed perhaps by the growth or accumulation of material upon the floor of the Gulf of Mexico, and he looks upon the formation of the Yucatan and Mosquito peninsulas as the counterpart of that fold on the southern face of the Gulf of Mexico. We should remember, however, that the Greater Antilles, as well as the Windward Islands, can scarcely be looked upon as part of the same counter thrust. They are of volcanic origin, and have an independent history of their own. Shaler certainly overestimates the amount of material now derived from Cuba, which finds its way to the Straits of Florida. At one time that must have been very considerable, as is well shown by the enormous denudation of its limestone mountains, but at the present day it is of little importance.[1]

A glance at the charts of the extreme southern part of Florida

[1] See A. Agassiz, "A Reconnoissance of the Bahamas," Bull. Mus. Comp. Zoöl., Vol. XXV. No. 1, p. 108; also, R. T. Hill, "Notes on the Geology of Cuba," Bull. Mus. Comp. Zoöl., Vol. XVI. No. 15, p. 267.

(Plate XVI.) cannot fail to impress one with the immense amount of disintegration which has taken place there. Leaving out of consideration the immense tract of lowland known as the Everglades, and concerning which we as yet know so little,[1] one can trace, proceeding southward, the gradual disconnection which has taken place between the Florida Keys and the mainland proper, while between Key Largo and Key Biscayne they are still united with the mainland at many points (Plate XII.), plainly indicating that they were a part of it after the elevation of the coral reef. When we go farther west it becomes more and more difficult to trace this former connection until to the northward of Key West, between it and Cape Sable, the extensive mud flats of the western part of the Bay of Florida, with here and there an isolated mangrove islet or a half sunken sand-bar, are all that give evidence of the former continuity of the land in the tract occupied by a line drawn between these points. In the triangle formed by that line, the keys, and the general line of the mainland from Cape Sable to Key Biscayne Sound, the evidence of the former connection becomes clearer and clearer in proportion as we proceed eastward (Plate XII.).

It is most probable that Key Biscayne Bay, Card's Sound, Barnes Sound, and the smaller sounds to the north of Key Largo, as well as a number of ill defined sounds between Barnes Sound and the Bay of Florida, owe their origin to the erosive and solvent action of the sea. A glance at the chart clearly indicates the former connection with the mainland of the line of keys extending from Key Biscayne to Long Key. The nature of this former connection is perhaps best seen at the two extremities of Key Biscayne Bay (Plate XII.). At its southern termination the tongues of land which divide Card's Sound into two basins still exist, as well as the narrow disconnected strips separating it from Barnes Sound on the south, while the dividing line between the northern extremity of Card's Sound and Key Biscayne Bay is barely indicated by the presence of the Rubicon and Arsenicker Keys. Similarly the Featherbed Bank and Black Ledge Bank (Plate XIII.) are the remnants of former strips of land, extending from the Ragged Keys to the mainland, which once divided Key Biscayne Bay itself into two or more sounds similar to those forming Card's Sound. These sounds may originally have been sinks similar to those of the Bermudas and Bahamas, and have, like those of these islands, been changed into sounds by the breaking through of the barriers separating them from the open sea.

[1] See the accompanying Report of Mr. L. S. Griswold on his examination of the southern extremity of Florida, page 52.

This would allow the gradual formation of more or less deep channels, slowly increasing in width and in depth, through which material held in suspension or solution could pass out and be deposited on the sea face of the sounds, the sea encroaching upon the shores of the sinks forming more and more distinct sounds, or even huge open bays like Key Biscayne Bay, separated from the sea by a barrier of sand bores completely covering the eroded part of the elevated reef which once flanked the bay from Key Biscayne westward, and of which Soldier Key, the Ragged Keys, and Elliott Key are the remnants (Plate XIII.).

Some of the larger and more extensive sinks characteristic of the southern part of Florida may be due to folding occurring at the time of the elevation of the reef forming the backbone of the larger Florida Keys. Yet some of the sinks and sounds undoubtedly owe their origin, not to the folding, as suggested by Mr. Griswold, but to the decomposition by water of the æolian rock deposited in the sinks, and to the subsequent disintegration due to the carrying off of limestone, either in solution or in suspension, through channels leading into open water.

Key Biscayne, Virginia Key, Soldier Key, and the Ragged Keys remain to attest the former existence of an extensive series of broad low keys, the position of which is indicated by the wide and shallow bank that separates Key Biscayne Bay from the waters of the Gulf Stream north of Sands and Elliott Keys (Plate XIII.). The numerous deep channels separating the banks to the westward of Key Biscayne undoubtedly indicate the position of cuts similar to Bear Cut, which divides Virginia Key from Key Biscayne. These keys have been eroded and the material which forms the sand bores that cover the sunken surface of the elevated reef has been brought by the currents from the low land which once occupied the interior of the sounds. The meeting of the sea, due to the prevailing winds, with the currents flowing out of Key Biscayne Bay has resulted in the deposition of the material they carry, the one on the sea face of that key, the other on the banks to the southward.

The spurs which extend in a northerly direction from the west side of Key Largo (Plate XII.), some of which extend to the mainland, plainly indicate the manner in which the line of keys has gradually become disconnected from the peninsula of Florida. The western part of Card's Sound is still separated from the sink of Barnes Sound by a continuous strip of land, and further by a series of smaller secondary sounds which will in time disappear with the erosion of the more or less disconnected dividing land strips. This will leave on that part of the flats only such

indistinct location of secondary sounds and sinks as may be indicated by the many spurs and tongues, and islets and shoals, or long irregularly shaped finger-like tongues of land, which abound in Barnes Sound, and to the east all over the flats of the Bay of Florida. In many cases the former connection of the keys with the mainland is only to be traced from the innumerable small isolated islands scattered over the Bay of Florida, in a line from Long Key to Cape Sable. In the part of the Bay of Florida to the westward of that line, as far as Pine Keys, the mangrove keys and islets, the remnants of the former easterly extension of the mainland, have disappeared, while the group of keys to the westward of a line passing through Bahia Honda (Plate XV.) attests the former eastern extension of the peninsula of Florida, which has disappeared through the same process now seen so actively at work in the district to the north of the outer line of keys from Long Key to Key Biscayne.

Sounds similar to those so prominent on the northeastern extremity of the chain of Florida Keys — viz. Barnes, Card's Sound, and Key Biscayne Bay (Plate XII.) — are repeated on a smaller scale from the Pine Keys to Key West as far as the Marquesas. An examination of the charts (Plate XV.) will show on many of the Pine Keys, Saddle Bunch Keys, Boca Chica, and Key West the mode of formation of smaller sounds; the disintegration of the larger islands leaving sometimes diminutive islands, or only narrow insular strips or angular spits and projections as remnants of the islands formerly limiting the sounds. These small and irregular sounds all discharge by so called creeks, Pelot's Creek, Sugarloaf Creek, and other outlets, which allow the piled up waters to escape and carry out the products of their disintegration of the island due both to solution and to mechanical action.

With the exception of Pine Keys, the surface of the keys from the Marquesas to Key Largo is but indifferently wooded (Plates II., III.), the vegetation consisting principally of a luxuriant fringe of mangroves (Plate IX.) and of low bushes, with occasionally a tree of larger size. On Key Largo and to the northward the trees are of larger size (Plate IV.).

Perhaps the most instructive part of the Florida Keys regarding the formation of sounds is that part of Key Largo (Plate XII., and Coast Survey Chart, No. 167) where we find the spurs indicating its former connection with the mainland, forming on the one side Barnes Sound and separating it from Card's Sound, and on the other Blackwater Sound, flanked on the east by Barnes Sound, on the north by three

smaller sounds, on the west by two, and on the south by Largo Sound; the land limiting these sounds being all parts of Largo Island, more or less connected, or separated by very narrow channels. It is easy to imagine such a sound as Blackwater Sound, with its fringe of land, becoming isolated and forming a cluster of islands very similar to that of the Marquesas.

On examining a prominent low bluff about a mile to the west of Miami River, I found to my great surprise that it consisted entirely of well stratified æolian rocks (Plate XIX.) the base of which had been changed into base rock. This base rock could be traced on both sides of the æolian bluff. On the east it extended to the mouth of the Miami River, and beyond, on both sides of the river, the exposures on the shores resembled the Bahama æolian rocks, being honeycombed, pitted, and full of pot-holes, and readily mistaken for reef rock. But I saw no corals in any of the exposures examined. Professor L. Agassiz found corals farther inland. The shore rocks on the southern edge of the mainland, where I examined them, are certainly not reef rock; they are of æolian origin, and the elevated reef on the rear of which these æolian beds were blown has disappeared. It now remains to be seen how far the reefs, or the belt of patches of reefs, of the southern extremity of Florida alternate with æolian rocks, and how far inland the latter extend, and what part of the Everglades they cover.

Both L. Agassiz[1] and Shaler[2] describe in detail the corals they have observed from one to three miles inland from the point I examined this time. Shaler describes the corals as a part of an elevated coral reef reaching a greater altitude than the reef which crops out at Elliott Key, and west as far as Indian Key. The bottom of Key Biscayne Bay near the northern extremity, about three miles from the entrance to the Miami River, is covered with Thalassia; the waters of the bay itself are of a dark brownish color, apparently saturated with vegetable matter. The dark color of the inland waters of the sounds back of the keys from Key Biscayne to Blackwater Sound is in marked contrast with the clear sea water which bathes the southern shores of the main line of keys. In some parts the bottom of the bay consists of fine dark gray sand, somewhat sticky. Near the shore Mr. Griswold has shown it to be covered with partly decomposed æolian rocks (Plate XX.). In the passage leading from Key Biscayne Bay past Cape Florida Lighthouse the bottom is hard, the current sweeping through with

[1] Mem. Mus. Comp. Zoöl., Vol. VII. No. 1.

[2] Bull. Mus. Comp. Zoöl., Vol. XVI. No. 7.

considerable velocity, and in our dredgings we brought up only a few specimens of coralline algæ, the current sweeping everything before it.

Soldier Key is the most easterly of the patches of elevated reef. To the north and south of it the reef has been partly eroded and partly covered over by the sand bores which flank the deep channels that have been cut through the elevated reef to give passage to the mass of water which pours out from Key Biscayne Bay (Plate XIII.). This is saturated with vegetable matter, and holds in suspension and in solution a great amount of lime, the former of which is deposited in the sand bores, and the other carried to sea, or perhaps precipitated under favorable conditions.

The shore of the sea face of Key Biscayne consists of siliceous sand, though a bank of coquina must be forming on an outside bar off the island, judging from the many fragments of it scattered on the beach. The siliceous sands form patches of solidified rock round the roots of trees and shrubs washed by the sea; some of these patches of harder material are of considerable extent, and appear at first sight like a bank of tubular sponges thrown up on the beach. The large amount of lime carbonate held in solution in the sea water undoubtedly forms with the siliceous sands the hard material mentioned above. Steaming parallel with the shore of the mainland we could follow the low rounded æolian hills flanking the sea face of the mainland from the bluff to the south of the mouth of Miami River to west of Cocoanut Grove. The hills are separated by narrow patches of mangrove swamps, similar to those we examined south of the mouth of the Miami River, where the æolian rocks barely reached the surface. It will be an interesting question to determine how far the "hummocks" are æolian hills,[1] and how far they are patches of the elevated reef, as well as to determine where the æolian hills crop out along the coast line of the mainland from Key Biscayne to Cape Sable, and how far inland they extend. We still have to determine how far the Everglades are a part of a great system of sinks formed, as were those of the Bahamas, by the disintegration, erosion, and solution of the æolian drift rock, and how far inland we can trace patches of a single or patches of a series of elevated reefs. What has been observed thus far along the line of the Keys, and along the southern edge of the mainland of Florida, by L. Agassiz, Shaler, and myself, seems to indicate the former existence of a wide belt of edging reefs and reef patches off the line of the mainland when its southern limit was

[1] See the Notes of L. S. Griswold, and the view I take of his observations, page 54.

probably that of a line nearly parallel with the sea face of the main line of keys, and about twenty or twenty-five miles inland. The reef extended along a coast lower than the coast of to-day, and has been elevated from six to twenty feet at certain points, and the material derived from the beach of this reef blown behind the reef has formed the line of the keys, or the flats, and filled the sinks, extending far to the northward. It is probable that the southern extremity of Florida only rose to a limited height. None of the dunes are more than twenty feet high, so that the work of erosion by the sea acted on an extensive area, and there must soon have been many passages cut by the currents across the present belt of the elevated reef and the adjoining land to form the series of islands which characterize the inner waters of the Florida Reef.

If it were possible to distinguish in the material which goes to form the bank off Cæsar's Creek the æolian and the reef rock, we might determine the extent of the coral reef, as well as that of the æolian ledges which must have been thrown up along the former beach of the now elevated coral reef.

Dall[1] states that Mr. Willcox found hard ringing æolian limestone about ten miles inland, southeast of Punta Rassa, so that the northern limit of the æolian district, forming part of the great series of sinks behind and within the limits of the elevated coral reef district of Florida, may have extended as far north as that point. When discussing the possible width and inland extension of the Florida reef in former times, we have several factors to take into account. Perhaps the most important one to limit the northern extension of the reef is the temperature of the water; another, the amount of fresh water and silt which may have been pouring out from the great sinks north of the reef; and finally, the nature of the connection between the great reef patches which form the belt of the Florida coral reef district.

In Australia, at the present day, we have in the Great Barrier Reef a belt of more or less disconnected reef patches, separated by deep channels, varying in width from two to three miles to more than seventy miles. Some of the patches being many miles in length and in breadth. The outlines of the patches which go to make up the belt of the Florida elevated reef can only be traced here and there, so that it is difficult to do more at present than to indicate in a very general way the district in which reef patches have been formed, or are likely to occur, but are now covered perhaps by æolian sands. The depth of the channels

1 Bull. U. S. Geol. Survey, No. 84, p. 101.

separating the patches of the elevated reef we have no means of measuring accurately now.[1]

The belt probably occupied by æolian rocks and reef patches I have indicated by cross ruling on Plate XVII. The lines of rivers indicated on the chart are only approximate lines of drainage, as the Everglade district has not been surveyed accurately.

The persistence of dunes composed mainly of siliceous sand along the east coast of Florida is natural, while it is equally natural to find that the dunes composed of calcareous sand from the parallel of Cape Florida have in great measure disappeared.

Professor Shaler rightly attributes to the southward movement of the siliceous sands along the east face of Florida and the adjoining keys the overwhelming of the northern extension of the reef, as well as the absence of flats, to the steepness of the shore formations. He thinks that a great part of the material between Lake Okeechobe and Cape Sable is probably made up of organic waste accumulated behind the coral reef. It seems to me more probable, from Mr. Griswold's observations, that the sand hills and the accumulation behind the reef are in great part of æolian nature, for the prevalence of easterly winds over the southernmost extremity of Florida is in marked contrast with the more variable winds of the northern regions of Florida. The existence of this sand does not, it seems to me, prove the submergence of the peninsula subsequently to the elevation of the coral reef. That appears to be the last disturbance in the general topography of Southern Florida.

The southern extremity of Key Biscayne marks the limit of the extension of the northern siliceous sand. Its limit can readily be traced on the charts by the nature of the soundings, and for a considerable distance south from the channel leading past Cape Florida into Key Biscayne Bay we find the bottom a mixture of siliceous and calcareous sand; the former driven by the prevailing winds into the channel south of Cape Florida, where it becomes more or less masked by the calcareous sand driven shoreward from the outer reef, and by the calcareous sand brought seaward over the reef separating Key Biscayne Bay from the waters of the Straits of Florida. (Coast Survey Chart, No. 166.)

Professor Shaler, in an interesting article on the "Topography of Florida,"[2] has given a very clear account of the immense disintegration

[1] Judging from the depth found within the main channel which separates the keys and the outer reef, these channels were probably comparatively shallow.

[2] Bull. Mus. Comp. Zoöl., Vol. XVI. No. 7, 1890.

going on in the Everglades by the action of rain water, and of the formation of the huge sinks which characterize that part of the southern extremity of Florida. He has, I think, suggested the manner in which we may imagine the great sounds like Key Biscayne Bay and Card's and Barnes Sounds to have originated. To this we must, I suppose, add the disintegrating effect of the action of the sea, as soon as a reach of any extent has been formed for the waves. With the prevailing northeasterly winds, the action of the sea must be very marked.

The outlets of the northern part of Key Biscayne Bay (Plate XIII.) are numerous, many of them broad passages. There is a wide pass between Soldier Key and the Ragged Keys, as well as passages between these keys and Sands and Elliott Keys. On each side of Soldier Key extends a broad sand bank, leaving ample room for the outlet of the waters of the western part of Key Biscayne Bay east of Elliott Key. Between Soldier Key and Cape Florida there are no less than ten deep, narrow cuts, kept open by the sweep of the tides, with from five to seventeen feet of water. Still farther to the northward, Bear Cut, which separates Key Biscayne from Virginia Key, is a comparatively broad passage, over half a mile wide, with from five to seventeen feet of water. On the north side of Virginia Key a narrow passage affords the northernmost outlet of the waters of Key Biscayne Bay.

The amount of the material which is brought by the outgoing currents on the outer banks of Key Biscayne Bay is seen not only in the sand bores to the northward of Soldier Key, towards Cape Florida, but also in the delta of Cæsar's Creek (Plate XIV.), a deep cut separating Elliott Key and Old Rhodes, which is the principal outlet of the southern part of Key Biscayne Bay. Through this cut pours all the material held in suspension or solution in the waters of the western part of Key Biscayne Bay. The creek is no less than three fathoms deep in parts, and runs in a bed of its own making nearly two miles out at right angles to the trend of the keys. The creek occupies the eastern edge of a triangular bank; the eastern slope of the bed of the creek is very abrupt, falling in a short distance, varying not more than from 200 to 300 feet, into ten feet of water, while its western slope runs very gently to the same depth on a slope a mile in width. The current of the creek has excavated a narrow bed, from seven to eight feet below the general level of the sea face slope of the keys, with a channel of from twelve to eighteen feet of water. The narrowness of the bank on the east side is perhaps due to the damming up of the overflow on that side by the prevailing easterly winds. A similar deposit on a smaller scale is formed

at the mouth of Tavernier Creek, off the eastern end of Long Island. (See Plate XII.)

On sounding off Cæsar's Creek, in ten feet of water, we obtained very fine sticky marl-like stuff. This comes from the region of flats behind Key Largo and Elliott Key, and is composed of the disintegrated material which once constituted the extension of the southern part of the mainland of Florida, and of which only the main line of keys and the isolated and scattered keys remain. These extend westward, becoming smaller and more widely separated as we proceed in that direction, and at the same time the southern shore line of Florida recedes more and more from the main line of keys.

A glance at the charts (Plate XII., also U. S. Coast Survey Charts, No. 10, and Nos. 167 and 168) will show this gradation in the disintegration of the southern extremity of Florida. To the northeast we have large and wide keys, like Elliott Key and Key Largo, forming the southern edge of Key Biscayne Bay, and still more or less connected with the mainland; next come the long narrow keys to the south of Barnes Sound, with here and there a spur running north; and finally we come upon a huge stretch of mud flats, with only an occasional islet or mangrove island, the northernmost boundary of which is Cape Sable, and of which the southwestern extremity is formed by the irregular spit of keys reaching from Long Key to the keys and banks to the westward of Key West and towards the Marquesas.

As we passed the mouth of the channel separating Grass and Duck Keys, a strong northwest wind blowing, we struck a huge fan-shaped stream of discolored water pouring out of the passage, clearly showing the mass of silt which, under certain conditions of disturbance, may rush out from the flats to the north of the keys, and when concentrated, as at Cæsar's Creek or off the line of keys and shoals south of Key Biscayne Bay, may form permanent deposits.

At Boca Chica (Plate XV.) we examined the quarry from which is obtained the material for building the jetties of the northwest channel out of Key West Bay. It was found to be æolian rock. About five feet above high-water mark it is riddled with tubes full of yellow sand (or often empty) in marked contrast with the surrounding white æolian sand. These tubes are often full of stalagmitic matter, filling the spaces formerly occupied by mangrove roots and slender stems which have become decomposed. Is this not the origin of many of the yellowish and irregularly shaped amygdules which characterize the hard ringing limestone into which æolian rock is so often transformed? The man-

grove roots and stems are still in place in the æolian marl near the landing to the quarry. There we find a thick bed of marl, — very similar to that off the west shore of Andros, — but it is filled in all directions with stems and roots and branches of mangroves, that form when decomposed the tubes mentioned above. It appears as if this marl had been formed by the blowing of masses of coral sand into the mangrove bushes growing in shallow water; the sand soon became consolidated, or indifferently so, and in this mass of marl the mangroves either continued to grow, or became overwhelmed by the small dunes. The marl off Andros may possibly have been formed in this way. Here the marl is full of small shells such as live in shallows, where they have been overwhelmed by the sand blown over them from the reef beaches. The marl off the south beach of Boca Chica, and at our anchorage in twelve feet of water, is similar to that of the west shore ; it is probably swept out by the tides, and is also carried northward by them.

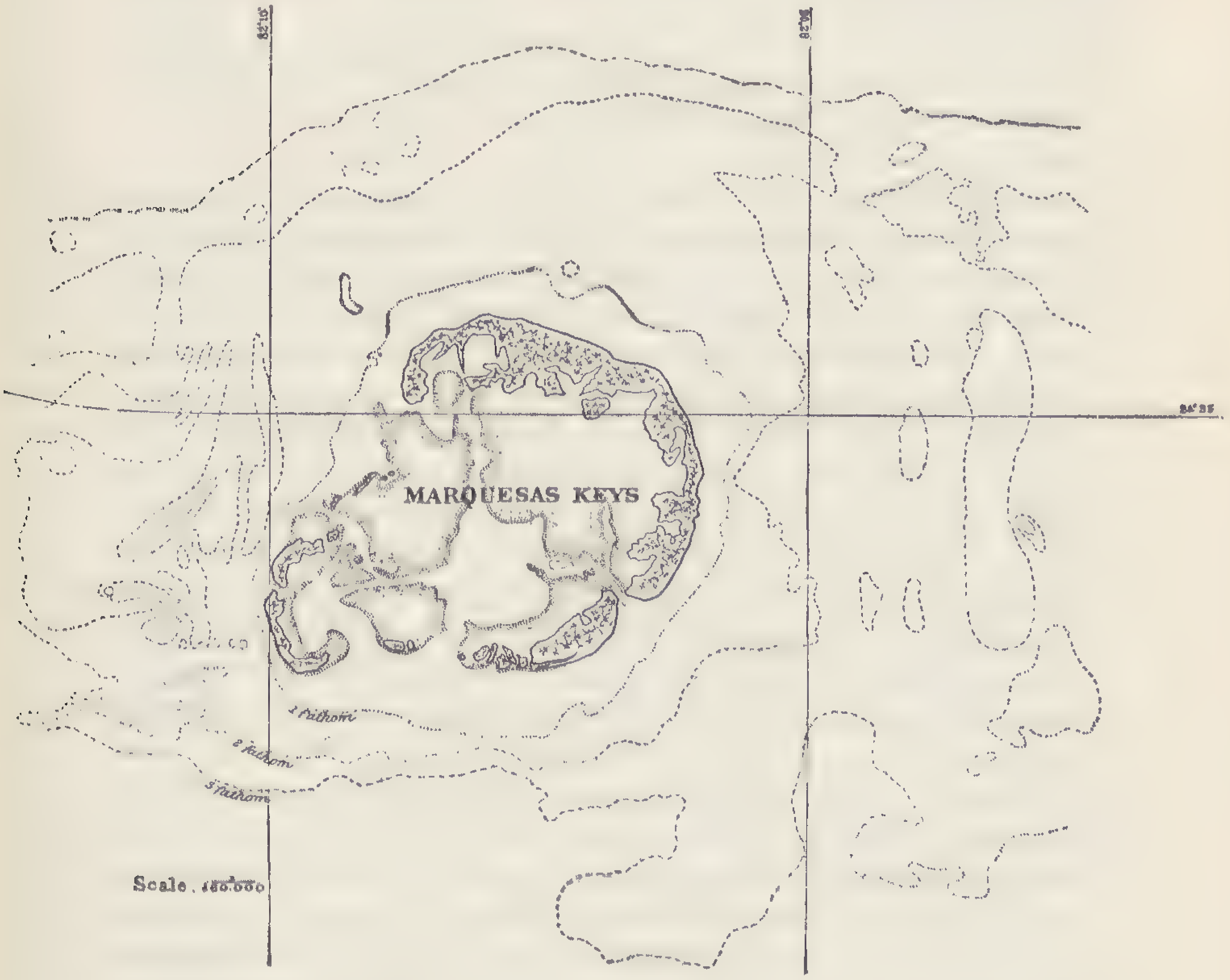
The condition of the northern part of Boca Chica is interesting, as showing what may probably have taken place all along the southern face of Florida, wherever there were sinks separating the flats of the elevated reefs, or deep patches or pools into which the beach sand derived from the reef could be blown. This æolian sand thus formed in shallow water deposits like marl, which gradually filled the mangrove swamps, and when rising above the surface formed low æolian hills standing in the very midst of reef patches.

With the light thrown upon the mode of formation of sounds along the northern portion of the Florida Keys, as well as from the formation of secondary sounds by the erosion and disintegration of smaller islands, like those to the eastward and westward of Key West as far as the Pine Keys on the one side and Boca Grande on the other, an entirely different conception of the formation of the Marquesas has been suggested.

I am now inclined to look upon the Marquesas as merely a broad circular sound, more complete than any other sound formed on the line of the keys, and not as an atoll. Being isolated, it is more striking than other similar circular sounds, which are more or less surrounded by incomplete sounds, spits, or isolated parts of islands, as in the Pine Islands and the islands immediately to the eastward of Key West (Plate XV.).

The islands forming the Marquesas group (Plates IX., X.) are separated by well marked passages, which I had formerly looked upon as the outlets of an ordinary lagoon till they had been raised well above

the general line of the Keys.[1] These passages give exit to the mass of material disintegrated from the small keys of the group. The bottom of the interior is naturally barren, being covered with a sticky marl, upon which grow mangroves and on which we find an occasional hole of Calianassa, a Limulas, or a skate swimming about, and Thalassia growing plentifully upon parts of the bottom.



May not the keys of the bank to the eastward of the Marquesas be merely the remains of similarly disintegrated land, the greater part of which has been eroded, leaving only the scattered keys between the Marquesas and the west side of Key West Harbor? (See Coast Survey Chart, No. 169.)

[1] A. Agassiz, "The Tortugas and Florida Reefs," Mem. Amer. Acad., 1883, Vol. XI. p. 118, Plate V. See also "Three Cruises of the Blake," Bull. Mus. Comp. Zoöl., Vol. XIV. p. 172, Fig. 44.

Boca Grande is in a condition which we may describe as a pre-atoll stage. On the sea face of Boca Grande there is a steep bank thrown up in front of a mangrove swamp occupying the southern part of the island. At the base of the bank a broad expanse of beach rock is exposed, dipping at a slight angle to the sea (Plate II.). The disintegration of the beach rock has supplied the material for the coral sand bank with its wide platform, which has been thrown up partly by the waves and partly by the winds. It is easy to imagine this bank broken through, with the sea making an irruption into the mangrove swamp and being transformed to an irregular atoll, but in fact a sound on a diminutive scale.

We find this to be the condition of Ballast Key, which represents an atoll stage. The coral sand bank has been broken through, and a strong current runs in and out of the gaps in the bank, and dunes have been formed on the weather side of the Key. The material for the inner dunes has been derived, as in the case of the Marquesas, from the patches and stretches of beach rock flanking the outer shore line of the coral sand beach. The outer shore line is composed of small mangrove beaches, interrupted by clusters of large mangroves. Here, as at Boca Grande, small mangroves are sprouting in the cracks and crevices of the beach rock. (See Plate II.) The bottom on the sea face is covered with similar blocks in all possible stages of disintegration. The same is the case elsewhere along the keys, on the shores of the sounds, and on the outer and inner reef flats. In a few feet of water masses of gorgonians and of sponges are growing profusely, and extend into deep water.

From this my last examination of the Florida Keys I am inclined to look upon the main line of the keys and of the patches of the outer reef as the remnants of a long and wide belt of stretches and patches of an elevated coral reef, which extended in more or less disconnected patches at the Tortugas, at the Marquesas, and from the Marquesas passage eastward to Key Biscayne, and even farther north, according to Shaler, as a submerged reef perhaps as far as Jupiter Inlet. The keys are all built upon this elevated coral reef foundation, which crops to the surface, as we have seen, at many points, and from the beaches on the sea face of this elevated reef has been obtained the oölitic material which as æolian sand has raised the keys to a height of sometimes ten to eighteen feet. This sand has been blown to the northward, and filled the sinks and sounds and channels separating the stretches of reef, and extended a considerable distance inland, to form low æolian hills and

bluffs between the patches and stretches of the old coral reef; or it has accumulated upon the top of patches and stretches of reef to form the higher keys, and this æolian rock has, little by little, either remained more or less mobile, or been solidified by rain or the action of sea spray, to form the hard ringing limestone of the main line of the Florida Keys.

From what we now know of the thickness of the reef from the borings of the Artesian well at Key West, the now elevated reef must have grown at no great depth upon the shallow shores of the Postpliocene coast of Southern Florida. The greatest depth upon which it began to grow was probably considerably less than the greatest depth at which reef corals are known to thrive. It was upon bars and flats at moderate depths, less than twenty fathoms, or upon their flanks, that the Postpliocene coral reef of Florida originated, — bars and flats extending from the edge of the outer reef of to-day probably far beyond the northern limit reached by Mr. Griswold in his exploration of the Everglades. Over the whole of this southern tract of the peninsula, wherever a coral sand beach was formed, æolian hills and dunes were blown consisting of coral sand oölite, or of coral sand more or less mixed with quartz sand, as we proceed northward and inland from Key Biscayne. These æolian hills and dunes have, little by little, been solidified into hard rock by the same agencies as those which changed into pitted and honeycombed limestones the stretches of æolian rock covering the land surfaces and sinks of the Bermudas, and the extensive areas of similar formation so characteristic of the Bahamas.[1] The territory covered in Florida by modified æolian rock within the range of the elevated reef and beyond it (see Plate XVII.) is not as extensive as the similar area of the Bahamas. In fact, it is of about the size of the Little Bahama Bank. But there is a marked difference between the two sides of the Florida Strait. In the Bahamas there has been a very marked subsidence since the formation of the æolian hills of that group, — a subsidence amounting perhaps to three hundred feet, while the elevated reef forming the substratum of the Florida Keys indicates a slight elevation since the formation of the æolian rock of Southern Florida.

Finally, it is upon the remnants of the old elevated reef that the present growing reef flourishes, forming, as it does in the Bahamas and Bermudas, a comparatively thin crust upon the underlying foundation rocks, which are now known to be Pliocene, and which occur at a depth considerably less than that at which reef corals are known to grow.

[1] A. Agassiz, "The Bermudas and Bahamas," Bull. Mus. Comp. Zool., Vol. XXVI.

Notes on the Geology of Southern Florida. By Leon S. Griswold.

(Plates XVII. to XXVI.)

The Ocean Border. — The southeastern extremity of Florida is protected on the side toward the ocean by an almost continuous line of narrow islands, — the Florida Keys. Between these islands and the mainland there is a continuous shallow water body, constricted for short intervals to a width of a hundred yards or less, but generally some miles in width, even to twenty-five miles. Bars and flats (Plate XXI. Fig. 1), with or without aerial vegetation, divide this large water area into a multitude of small sounds. In many places, at depths of five to twelve feet, the floor of these sounds is rock; the floor is not smooth, yet affords no anchorage. An idea of the sea floor may be had from Plate XVIII. of the shore at Cocoanut Grove at half tide. (See also Plate II.)

The Foundation of the Mainland. — On approaching the mainland on Key Biscayne Bay the rock floor comes near the surface, so that specimens may be obtained. The rock is no longer elevated reef, but a fine grained oölitic limestone, containing occasional shells and supporting a growth of southern pine. Shore line bluffs and vertical sections obtained inland show stratification clearly, and for the most part cross-bedding. (Plate XIX.[1]) The deepest section obtained, sixteen feet in a well at Cocoanut Grove, showed numerous fragments of coral at the bottom. This would tend to indicate that the oölite covers a reef. The bottom of the well is about at sea level, and variations in the height of the sea water affect the depth of water in the well. This fact is general at Cocoanut Grove.

If we can assume a broad reef as underlying the oölite, then there is a long narrow uplift along the line of great keys, or there is a line of dislocation just on the west side of these keys, the upthrow being to the east. Analogy with the phenomena of the mainland would favor the idea of folding.

The Pine Belt. — The rise of the oölite from the sea is gradual, varying up to about four feet in a hundred. Bluffs even ten or twelve feet high occur where conditions are favorable for shore cutting, and there are old bluff lines now protected by marsh. The bluff condition prevails for some miles south of the Miami River; north and south of this

[1] This bluff is a most distinctly marked æolian rock exposure, with characteristic knife edge stratification. — A. Agassiz.

locality the rise is gradual, commonly from a coastal swamp (Plate XX.). Inside of Key Largo the coastal swamp is ten or twelve miles wide. The oölite rises to an elevation of about twenty feet, and then maintains a generally level surface, with the exceptions of occasional broad undulations, having axes about east to west or north to south, and sinks. The hollows of the broad undulations are filled with water during the rainy season, so that pines do not grow in them ; in the dry season grass grows luxuriantly, and some of the sinks are cultivated. Some soil has accumulated in these "prairies," whereas among the pines there is scarcely any soil to hide the jagged rock surface and loose fragments (Plate XXI. Fig. 2). The sinks are sometimes of rounded form, with perhaps a maximum diameter of two hundred feet, or linear, a few hundred yards in extent. It is locally believed that the underground streams associated with the sinks drain not only the pine land, but help to drain the Everglades to the west, because great springs of constant flow emerge in large numbers along the shore. This is probably true, but the interior drainage perhaps escapes by percolation, or very small channels, for no sinks were seen in or near the Everglades. The pines cover a shore strip about six miles wide between New and Miami Rivers, then widening to about fifteen miles in the next twenty-five miles toward the southwest. The southwestern terminus of the pines is not known.

The Everglades. — A great area of Southern Florida west of the pine belt comprises the Everglades. The cause of the Everglades would seem to be similar to that for the prairies among the pines, — a drainage so defective that much water accumulates during the rainy season, and some even continues through the dry time, though the change in elevation is perhaps two feet. Temporary surface channels to the sea help drain the Everglades during the rainy season, but only the larger rivers, as the Miami and New, flow throughout the year. The rivers have a well marked fall line on the limestone, — a few hundred yards of swift water just west of the pines, and representing the progress made by the rivers in cutting back from their mouths.

At the border of the Everglades the rough surface of the oölite becomes concealed for the most part beneath a mat of grass, and pines grow no farther west (Plate XXIV. Fig. 1). In the zone of oscillation of water the grasses change in character from a small wiry variety near the pines to saw-grass six feet or more tall, and flags and cane growing in water. The Everglades impress one as a sea of grass growing in shallow water, with countless shallow ponds of clear water in which grow

small bulrushes, lilies, and other water plants; the ponds are of most irregular and confusing shapes, so that it is a matter of much difficulty to travel twice over the same route; ponds may have wide connections, narrow connecting channels almost entirely hidden by saw-grass, or may be shut in by saw-grass completely. Oftentimes a tall man is unable to see a pond close at hand, so thick and high is the saw-grass. Scattered about in this sea of grass are islands of bushes and trees, called Keys. These keys seem to owe their origin to an accumulation of vegetable matter which may appear some inches above water level, during the dry season becoming partially dry (Plate XXIII. Fig. 2). During a night's sleep upon them one's bed is liable to settle to water level, and it is a common experience to break through to the knee in walking over them without feeling a firm foundation; it is probable that the mat of grass roots or peat is what stops one's downward progress.

Origin of the Oölite. — The low undulations of the land surface in the pine belt can scarcely be accepted as evidence of former dunes. They would well accord, however, with the inequalities of a sea floor like the present one between the keys and the mainland. The cross-bedding and oölitic structure favor neither water nor wind as the primary agent in the construction of the rock. Therefore, since the land appears to be very young, being almost without soil and surface drainage ways, the topography favors an origin for the limestone in water. Elevation was apparently accompanied by slight folding, thus giving opportunity for the pine belt to develop and favoring the formation of a line of keys, in shallower water in the Everglades, approximately parallel with the edge of the pines and distant a few miles. This line of keys in the Everglades diverges southwestward from the pine belt just as the pine belt does from the elevated reefs.[1]

1 It seems to me that Mr. Griswold is mistaken in ascribing an aqueous origin to the oölitic limestone he collected from the Everglades. From what I saw myself of this limestone along the shore of Key Biscayne Bay, the rocks, which are the same as those collected from the inland by Mr. Griswold, consisted entirely either of patches of honeycombed æolian rock or of weathered elevated reef coral limestones, the æolian rock having been blown into sinks, as I observed it at Boca Chica, so as to fill them, and as dunes rising to eighteen or even twenty feet on higher parts of the mainland. The decomposition and disintegration of the Everglades seems to me to indicate merely a later stage of disintegration, and one similar in every way to that going on between the keys and the present shore of the Florida mainland, a disintegration and decomposition affecting rocks of the same age and of the same constitution, — viz. æolian and elevated coral reef rocks, — and going on along the edges of the greater or smaller sinks, filled with æolian sands, which separate the different parts of the elevated coral reef. Some of the

Notes upon Specimens. — At Mr. Rhodes's quarry, Cocoanut Grove, is found a fine white oölitic limestone containing occasional small shells. The oölite grains are about half a millimeter in diameter. The oölitic structure can be determined by the eye, though a microscopic examination of a thin section is necessary for details. There is a nucleus usually of calcareous substance of more or less irregular form, apparently a detrital grain, about which have been formed a few rings or a shell of similar substance; sometimes a radiating fibrous structure is faintly shown between the rings, and also in the rock cement. Small angular grains of quartz are abundant also as nuclei.[1]

Surface specimens obtained in the same region, as far inland as fifteen to twenty-two miles from the coast, show similar composition and structure, though the oölitic character has been somewhat obscured, apparently by surface changes. Specimens obtained below the surface, in natural wells and from river banks, show good oölitic composition. This is true as far north as New River, and would give the oölite an extension north and south of at least sixty miles; it is at least thirty miles wide in the vicinity of Cocoanut Grove, and fifteen miles at New River.

Thirty miles north of New River, in the vicinity of Linton, there is a cross-bedded fragmental rock, probably representing the northward extension of the oölite. The quartz material is more abundant, however, and of coarser grain, and the oölitic structure is not common, and the oölite grains are smaller. Specimens from the canal at Linton show oölite interbedded with coquina. Still farther north, about Lake Worth, there is rock resembling that at Linton, with rare traces of oölitic structure. A specimen of a friable rock from Cape Canaveral, which may be homologous, shows quartz predominating and considerably coarser in grain. Traces of oölitic structure are found. Coquina abounds here and to the north.[2]

Contemporaneity of Oölite and Coquina. — The interbedding of coquina and oölite at Linton, the close association of the two rocks observed

more regularly stratified oölitic rocks are also the remnants of extensive coral beach rocks laid down dipping at a slight angle to the sea (6° to 10°) flanking the keys and flats interspersed between the stretches of the elevated coral reef. Such beach rock as is characteristic of Loggerhead Key, the sea face of Key West (Plates I., V.), and of many other keys. — A. AGASSIZ.

[1] The oölitic structure described by Mr. Griswold applies in every way to æolian rock blown from a coral reef sand tract. — A. AGASSIZ.

[2] The presence of quartz particles shows how far inland the shore quartz sands are carried by winds, just as this quartz sand can be detected south of Key Biscayne. — A. AGASSIZ.

about Lake Worth, and the suggestion of the oölite at Canaveral, where coquina prevails, lead to the belief that the oölite of Southern Florida is contemporaneous with the coquina of the north.[1]

Itinerary. (Plate XVII.) — I left Boston on February 10th, travelling as rapidly as possible to Cocoanut Grove. The railroad had not been opened beyond Palm Beach when I went down; at the time of my return it was open to New River. Travel by boat beyond Palm Beach was slow. The route lay through the new canal, which completes an inside passage from Lake Worth to Biscayne Bay. Along the canal were seen masses of coquina, and in places an æolian-like rock which had been taken from the canal.

In a walk of some miles about Cocoanut Grove I saw no evidences of any formation other than a stratified rock, which proved to be an oölitic limestone.[2] There is a local belief, however, that large heads of coral occur and that the country is largely elevated reef. I felt incompetent to pronounce final judgment without having seen true elevated reef; and as there would be delay in securing a canoe for the Everglades, I decided to hire a man and boat and see something of elevated reefs and the coast line. I saw elevated reefs on Soldier and Elliott Keys, then followed the inside passage back of Key Largo (Plate XXII.) to Florida Bay, sailing among the keys and beyond Cape Sable. The waters of the region are shallow, and abound in flats and bars of great extent, many of which could not be crossed by our boat of six inches draught except at the narrow tide channels. In some of these tide channels, and often in the sounds between bars, rock bottom could be felt at eight to ten feet. The bars, flats, and keys, however, showed nothing more than mud or sand; among the inside "keys" no land that is permanently above water is known to my boatman. I was afterwards told that Lignum Vitæ Key was in part high; if this is true, it is the only high one in the northern half of the chain that lies west of the main line of keys.

Cape Sable and vicinity is a mass of shells and shell fragments thrown up by waves and wind above the highest water. A charcoal burner near Middle Cape stated that the shell beach extended to Northwest Cape; and he knew of no rocks inland. East of East Cape the beach becomes lower; a charcoal burner ten miles east knew of no rocks.

[1] The contemporaneity of coquina and of the oölitic rock (æolian) had already been observed by Professor Shaler. Bull. Mus. Comp. Zoöl., Vol. XVI. No. 7, p. 143. — A. Agassiz.

[2] Æolian rock? — A. Agassiz.

Still farther east mangrove swamp formed the shore edge, but for a distance of about twenty-five miles the shore was not seen, and was unknown to my boatman. It is probably a low mangrove swamp. Beyond this unknown part, to the northeast, the entire shore line is mangrove or grass swamp to Cutler, a small settlement on Key Biscayne Bay about twelve miles south of Cocoanut Grove, where the limestone reaches the shore. This rock continues at or near the shore from this point northward. Southward from Cutler the border of outcropping bears to the west, so that it becomes more and more distant from the shore.

A canoe, already on the border of the Everglades, had been secured during my absence, and an advantageous start was made by transporting provisions, etc. about eight miles over land. Indians could not be had as guides, so I retained my boatman, who was a strong young fellow, and knew as much about the Everglades as any one. The water in the Everglades was lower than I had supposed from previous reports.

The objective point being Long Key[1] of the Everglades, our course was turned southwest as soon as we found sufficient water. After about nine miles progress in this direction, the water becoming more and more shallow, and progress only possible by means of an Indian trail (Plate XXIII. Fig. 1), an unpromising expanse of liquid mud and saw-grass persuaded us to return. We were not more than three miles distant from the pines at any time; rock bottom could be touched anywhere through the mud.

A line of keys extending northeast to southwest lay to the west of our course, and we tried to find a way through them; we had no success until we had gone back on our course about six miles. Then a passage was forced across this stubborn divide, perhaps a few inches in height. On the other side was abundant water, and we turned southwest again on the west side of what is apparently the foundation ridge of Long Key. Indian hunting camps were passed and conversation held with the Indians. They do not like to have white men in their country, but do not molest them. Again the water became shallow, openings in the saw-grass were without water, and we were obliged to turn back northeast, though trying every chance to go westward. On this line we reached perhaps eighteen miles from our starting point and fifteen from the coast. Rock foundation was everywhere within touch through the mud, and often visible. A specimen of rock was secured near the most distant point we reached.

The waters of the North Fork of the Miami offered the next chance

[1] Not to be confounded with the Long Key of the main line of keys.

to get into the interior; we had been previously on the South Fork. The same broad low divide supporting numerous keys (Plate XXIV. Fig. 2) was crossed by shallow channels of water running over a siliceous sand which covered the rock about a foot, so we had little difficulty here. We found, however, that we could go only in a general northwest direction. Even then we should have been very probably obliged to give up our route had we not discovered a fresh Indian trail. We followed this for nearly two days, tracing it with ease through the grass, but having many sharp hunts where open water was crossed (Plate XXV. Fig. 2). Finally, the trail was completely lost, and mud ways in the saw-grass were all that were left to us. We were thirty miles or more from the coast; an unbroken expanse of grass with small bushes extended to the west (Plate XXV. Fig. 1), and to the east only one or two keys were faintly visible. The rock foundation had been traced by soundings with a pole through the mud. Its distance below the water surface varied between three and six feet; at our most distant point it was five feet.

During high water one might frequently sail in the Everglades, and exploration would be much more rapid.

One more possibility of reaching Long Key presented itself, — to go across the pine belt south of Cocoanut Grove to the edge of the Everglades, and then see what might be done. I went along the shore in a canoe, with the same man as guide: the limestone was within easy reach under water for most of the time. A little south of Cutler, at the locality called the Hunting Ground, an examination of natural wells and sinks made by the falling in of the roofs of underground channels showed only stratified limestone to water level. The deepest sections were perhaps twelve feet. About twenty miles south of Cocoanut Grove we entered a small creek, and worked up its tortuous course some miles to the edge of the pines. A rough walk of perhaps eighteen miles brought us to the edge of the Everglades. By burning the grass, I was enabled to go some three miles farther west (Plate XXVI.). This point was about twenty-three miles from the coast; to the west could be seen numerous keys, the nearest small one being half a mile away, while at a distance of four or five miles there appeared to be a key continuous from northeast to southwest, perhaps the reputed Long Key, but the occurrence of numerous intermediate keys rendered belief in its continuity uncertain. The aspect of the Everglades here was similar to that farther north, — the rock foundation was dipping gradually westward below the water level, and the keys were low islands of vegetation

similar to those seen elsewhere; even on the supposed Long Key no pines could be seen, as would be expected if the foundation reached high-water mark. I assumed, therefore, that the difficulties involved in going farther west would not be repaid by any new results, and accordingly returned to Cocoanut Grove.

A number of sections shown in natural and artificial wells about Cocoanut Grove were examined. Everywhere the evidences of bedding were clear. In the deepest section, however, about sixteen feet deep, stratification became obscure toward the bottom, and the material, instead of being uniformly fine grained, contained numerous small fragments of coral. It would seem as though the reef must be near at hand. The ordinary fine grained limestone appears oölitic, and a small quarry offers clean specimens that show this structure well.

Thinking that some notes on the northern extension of the oölite along the east coast of Florida would be of value, I made a few observations on my way north. At Lemon City, twelve miles north of Cocoanut Grove, the rock may be identified at the boat landing. It is thrown up along the canal ten or twelve miles north of Lemon City.

At New River, thirty miles north of Cocoanut Grove, another section was made into the Everglades. In a day's trip a point sixteen or eighteen miles from the coast was reached; lack of water prevented further progress. Sounding through mud five feet failed to give rock bottom, and the last rock noted was perhaps twelve miles from the coast. The rock was similar to that farther south.

About thirty miles north of New River, at Linton, another examination was made. A cross-bedded fragmental rock was abundant, but contained considerable quartz. Coquina was also abundant, and the two rocks were found interbedded.

At Palm Beach and vicinity the coquina and fine fragmental rock also occur closely associated: the coquina perhaps predominates. This is about twenty miles north of Linton. At the last two localities inquiries gave no encouragement to inland exploration.

A trip to Cape Canaveral disclosed there a rock which may well represent the fine fragmental rock of Palm Beach and Linton. The quantity of quartz is greater, the quartz grains are larger, and the rock less coherent than to the south.

EXPLANATION OF THE PLATES.

PLATE I.

Coral Sand Beach, Key West, Florida.

PLATE II.

Beach Rock partly covered with Coral Sand, Boca Grande.

PLATE III.

Vegetation, Boca Grande.

PLATE IV.

Coral Sand Beach, between Patches of Elevated Reef, Elliott Key.

PLATE V.

Coral Sand Beach Rock, South Shore, Key West.

PLATE VI.

Elevated Reef, Indian Key.

PLATE VII.

Elevated Reef, Indian Key.

PLATE VIII.

Elevated Reef, Eastern Extremity of Elliott Key.

PLATE IX.

Part of Eastern Arc of the Marquesas Islands.

PLATE X.

Part of Western Arc of the Marquesas Islands.

PLATE XI.

Lagoon, North Shore of Key West.

PLATE XII.

Sounds to the Westward of Key Biscayne Bay.

PLATE XIII.

Key Biscayne Bay.

PLATE XIV.

Cæsar's Creek Bank.

PLATE XV.

Islands to the East of Key West.

PLATE XVI.

Southern Extremity of Florida and Florida Keys.

PLATE XVII.

Southern Extremity of Florida, showing the Route of L. S. Griswold.

The area covered by cross ruling indicates the probable extent of the Florida Reef belt. — A. Agassiz.

PLATE XVIII.

Shore at Cocoanut Grove, Low Tide.

PLATE XIX.

Æolian Bluff, Key Biscayne Bay, near Miami.

PLATE XX.

Border of Pine Land on Coastal Prairie.

PLATE XXI.

Fig. 1. Card's Sound. Mainland in the distance. Young Mangroves on Bar.
Fig. 2. Border of the Everglades, showing Æolian Rock.

PLATE XXII.

Inside Passage west of Key Largo.

PLATE XXIII.

Fig. 1. Indian Trail in the Everglades.
Fig. 2. Keys in the Everglades.

PLATE XXIV.

Fig. 1. Edge of the Everglades.
Fig. 2. Key in the Everglades desolated by Winds.

PLATE XXV.

Fig. 1. Looking West over the Everglades. Shallow Water over Mud. Indian Smoke on the Horizon.
Fig. 2. Open Water in the Everglades.

PLATE XXVI.

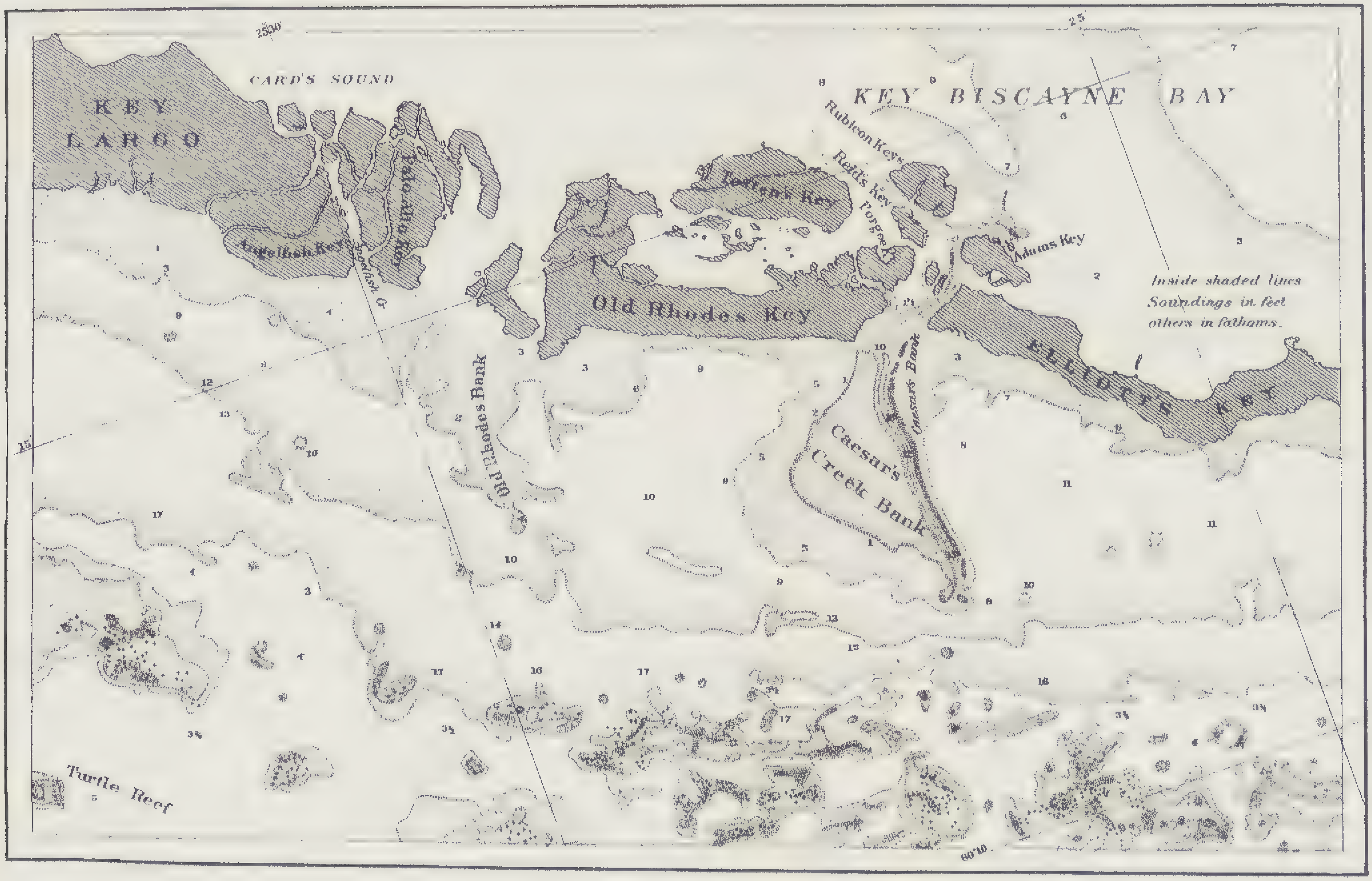
Edge of the Everglades showing Honeycombed Limestone Rock, exposed by burning the grass.

Plates XVIII. to XXVI. are from photographs taken by Mr. Griswold.

B. Meisel, lith.

From U.S. Coast Survey Coast Chart No. 10.

B. Meisel lith. From U.S. Coast Survey

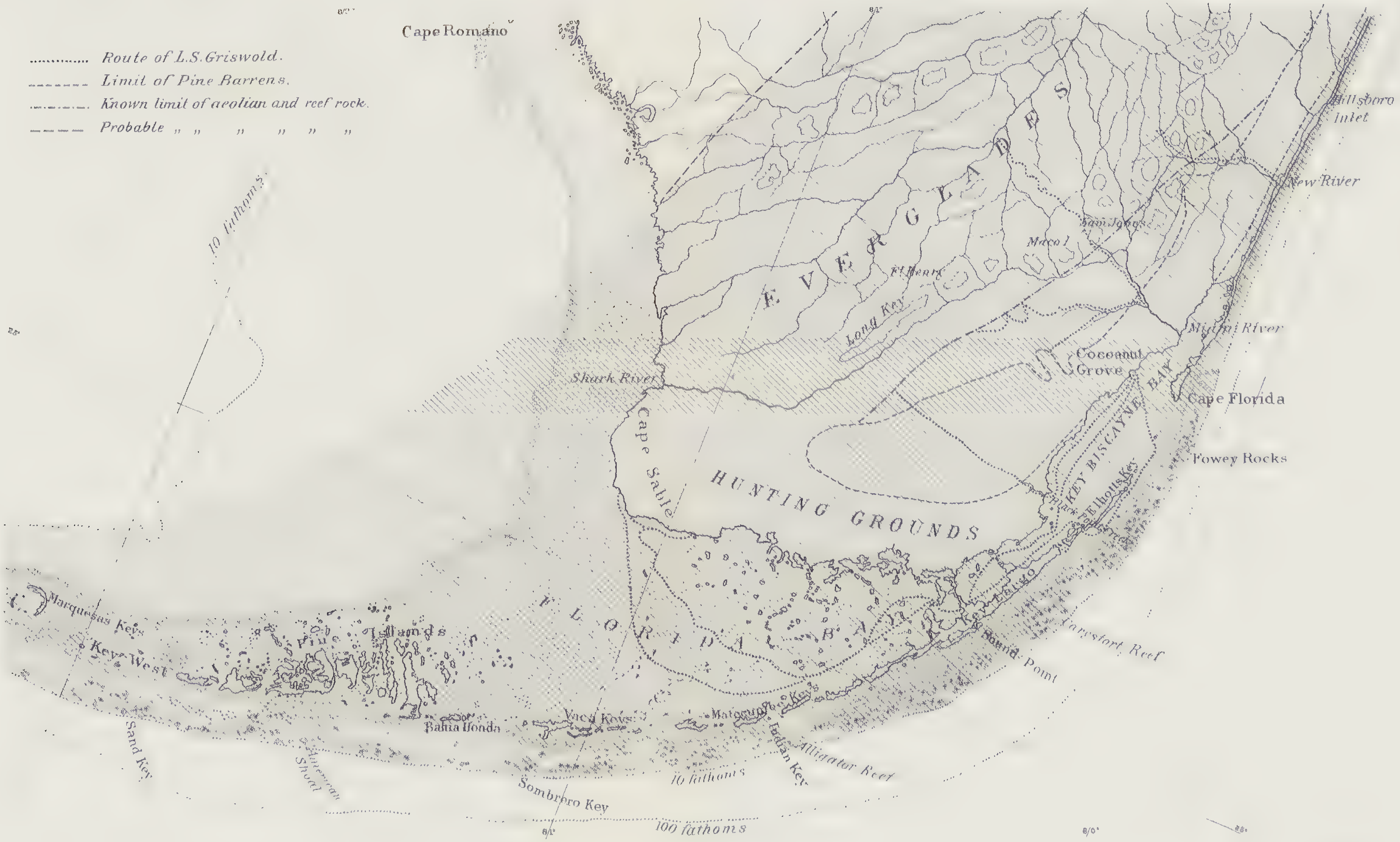


B Meisel, lith

From U.S. Coast Survey Coast Chart No. 69.

STRAITS OF FLORIDA

from Coast Survey Charts.



B Meisel lith

CORAL SAND BEACH, KEY WEST.

ARTOTYPE, E. BIERSTADT, N. Y.

BEACH ROCK PARTLY COVERED WITH CORAL SAND. BOCA GRANDE.

VEGETATION, BOCA GRANDE.

ARTOTYPE, E. BIERSTADT, N. Y.

CORAL SAND BEACH BETWEEN PATCHES OF ELEVATED REEF. ELLIOTT KEY.

ARTOTYPE E. BIERSTADT, N. Y

CORAL SAND BEACH ROCK, SOUTH SHORE, KEY WEST.

ARTOTYPE E. BIERSTADT N.Y.

ELEVATED REEF, INDIAN KEY.

ARTOTYPE, E. BIERSTADT, N. Y.

ELEVATED REEF, INDIAN KEY.

ARTOTYPE. E BIERSTADT, N. Y.

ELEVATED REEF. EASTERN END OF ELLIOTT KEY.

ARTOTYPE, E. BIERSTADT, N. Y.

PART OF EASTERN ARC OF MARQUESAS ISLANDS.

PART OF WESTERN ARC OF MARQUESAS ISLANDS

LAGOON, KEY WEST, NORTH SHORE.

SHORE AT COCOANUT GROVE.

L. S. GRISWOLD. PHOTO

ARTOTYPE. E. BIERSTADT, N. Y.

AEOLIAN BLUFF, KEY BISCAYNE BAY NEAR MIAMI.

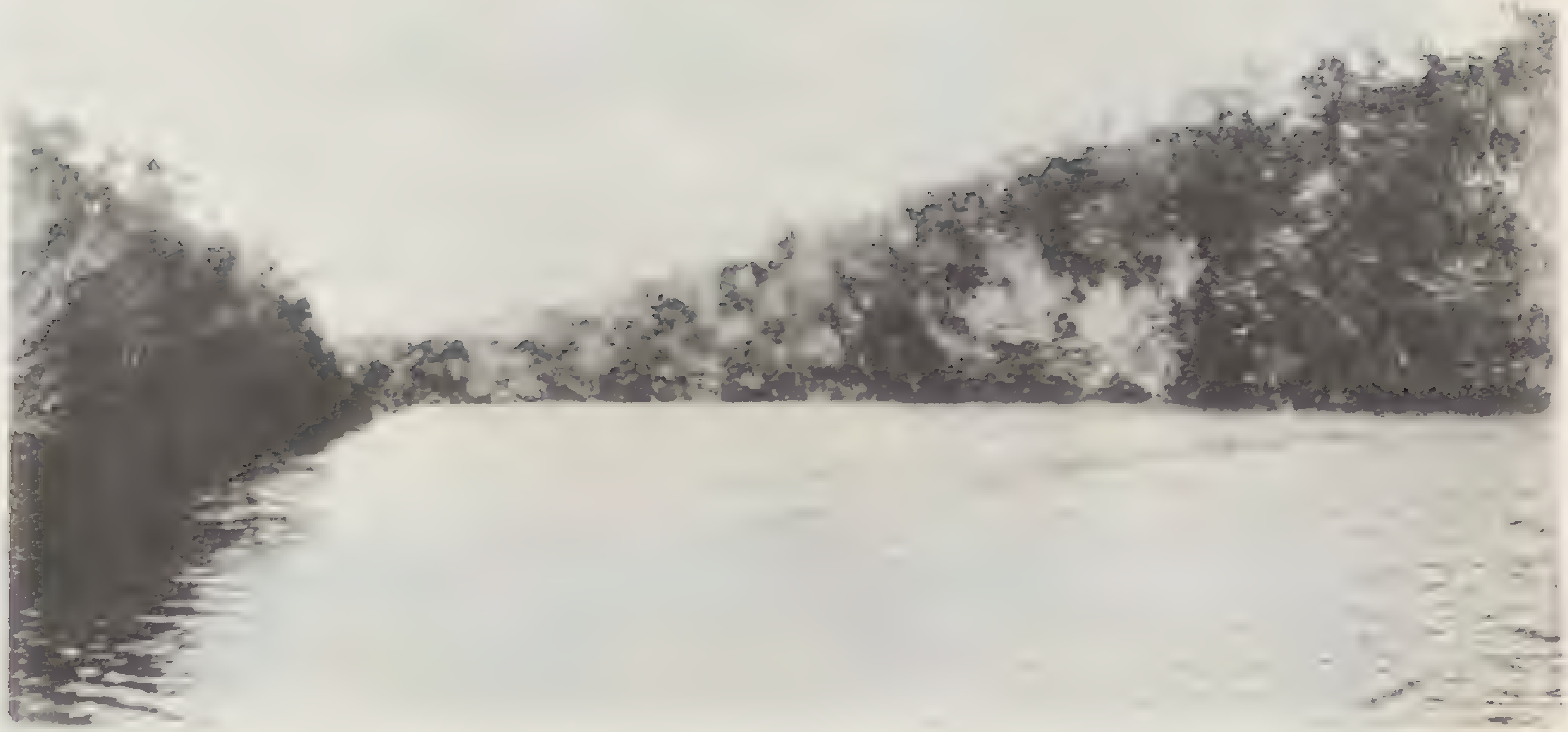
L. S. GRISWOLD, PHOTO. ARTOTYPE. E. BIERSTADT. N. Y.

BORDER OF PINE LAND ON COASTAL PRAIRIE.

CARD SOUND. FLORIDA SHORE IN THE DISTANCE.

ARTOTYPE E. BIERSTADT, N. Y.

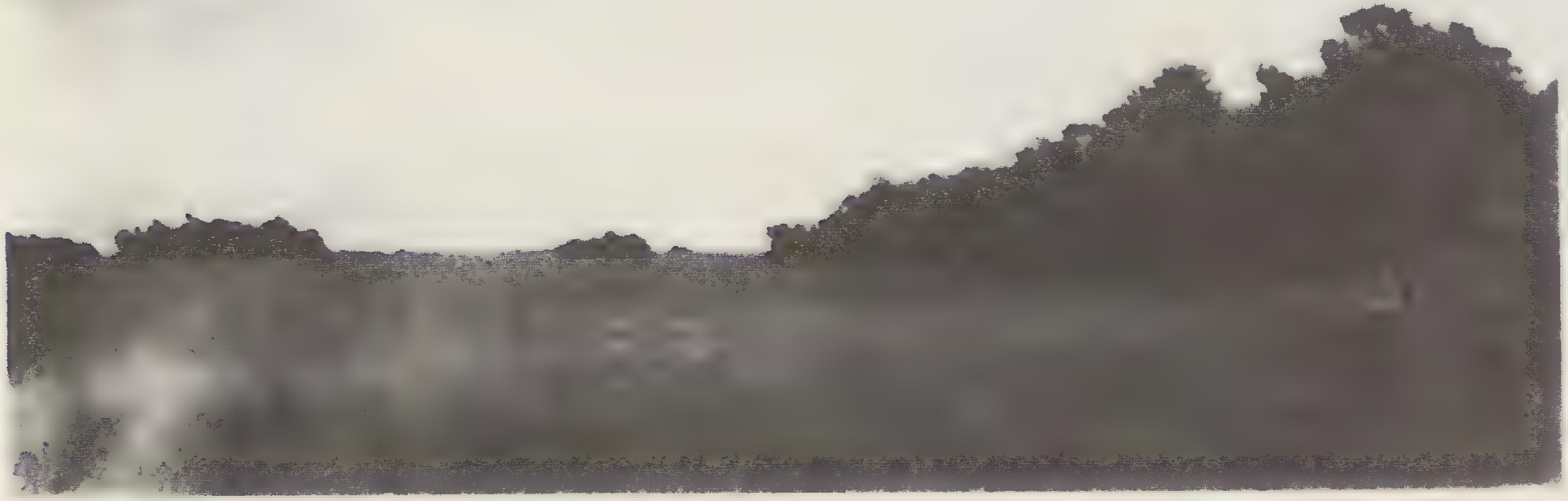
BORDER OF EVERGLADES.



L. S. GRISWOLD PHOTO. ARTOTYPE. E. BIERSTADT, N. Y.

INSIDE PASSAGE, WEST OF KEY LARGO.

INDIAN TRAIL IN EVERGLADES.



L. S. GRISWOLD. PHOTO. ARTOTYPE. E. BIERSTADT. N. Y.

KEYS IN THE EVERGLADES.

EDGE OF EVERGLADES.

L. S. GRISWOLD. PHOTO. ARTOTYPE E. BIERSTADT, N. Y.

KEY IN THE EVERGLADES.

LOOKING WEST OVER THE EVERGLADES.

OPEN WATER IN THE EVERGLADES.

EDGE OF EVERGLADES SHOWING HONEYCOMBED LIMESTONE ROCK.

Bulletin of the Museum of Comparative Zoölogy

AT HARVARD COLLEGE.

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NOTES ON THE ARTESIAN WELL SUNK AT KEY WEST, FLORIDA, IN 1895.

Based upon a Collection made for ALEXANDER AGASSIZ.

BY EDMUND OTIS HOVEY.

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DECEMBER, 1896.

No. 3. — *Notes on the Artesian Well Sunk at Key West, Florida, in* 1895. By Edmund Otis Hovey.

In 1895 an Artesian well was sunk at Key West, Florida, to the depth of 2,000 feet. Samples of the borings were taken every 25 feet from the surface to the bottom, and through the kindness of Mr. Alexander Agassiz a set of these samples was placed in my hands for microscopic examination. The petrography of the material passed through is simple. It is all an almost perfectly pure lime-rock, and is a typical oölite at the surface and at 25 feet below. Beneath that depth most of the samples indicate a fine or coarse, more or less loosely compacted sand-rock, relieved somewhat by beds or masses of compact limestone or porous rock. Small bits of oölite, or loose ovules, are present in about half of the samples, indicating a shallow water origin for much of the material. The most solid rock of all passed through seems to come from the depth of 50 to 175 feet from the surface, inclusive.

Perhaps the most peculiar petrographic feature is the presence in all the samples except three (25, 50, 1,375 feet) of a small amount of quartz. This varies from the merest trace up to a very noticeable proportion, and is sometimes visible under a one-inch hand lens. About two grams of each sample was carefully dissolved in hydrochloric acid, and the residue washed and examined under a compound microscope. This residue consisted mostly of a very fine-grained angular sand, having the lustre and fracture of quartz, and scratching glass with ease. Some of the grains suggested the hexagonal outlines and pyramidal termination of crystals, but none was definitely made out. The particles were perfectly limpid and showed no effects of abrasion. With this angular sand were sometimes associated a few well rounded grains of clear quartz of much larger size. Frequently the rounded grains were too coarse to pass through a No. 40 mesh sieve, but this was never the case with the angular material. It seems probable that the fine grained, angular quartz is of secondary origin by infiltration of siliceous waters. That the waters percolating through the rock strata of Florida carry silica in solution, is clearly indicated by the chalcedonized Miocene

corals from near Tampa, on the west side of the peninsula. The rounded grains, which are much fewer in number than the others, are evidently transported particles and must have come from a distance, since such quartz is not indigenous to any rocks in the vicinity of Key West.

The angular quartz sand was present in largest amount at the following depths: 250 to 325 feet inclusive, 400 and 425 feet, 800 feet, and 1,250 feet. The least was seen at the surface, at 25 and 50 feet (none), 100 feet, 150 feet, 725 feet, 775 feet, 850 to 1,225 feet inclusive, 1,300 feet, 1,325 feet, 1,375 feet (none ?), and below this there is only a trace in each sample.

With almost all the samples a flocculent precipitate settled out of the HCl solution after a time. This varied in color from a very light gray through brown to a greenish black. The nature of this precipitate was not determined.

The surface oölite, though friable, was sufficiently compact to yield a thin section. The nuclei of almost all the ovules are rounded or subangular calcareous grains. One ovule was observed the nucleus of which was a grain of quartz. The matrix of the oölite is very finely divided soft rock, composed of entirely unrecognizable material as far as any organic remains were concerned. The surface rock, in fact, and that from 25 feet as well, seem to be entirely devoid of determinable organic fragments. Small lumps of oölite or loose ovules were noted in about half of the samples scattered along from top to bottom. The upper half of the section is more oölitic than the lower, and the upper 500 feet more than any other portion. In appearance the ovules differ from ordinary rounded grains of sand in being more regular in outline and in having the exterior more highly polished. Many of these highly polished, regular ovoids were cracked open with a light blow of a hammer, or by pressure on a glass plate, thus revealing the concentric shells characteristic of true oölitic structure. To the present writer it seems important to confine the term oölite to rocks composed of these concentrically built spherules embedded in a matrix, and not to extend it as some writers are inclined to do to rocks made up merely of well rounded fragments embedded in a more finely comminuted matrix.

Organic remains which retain sufficient character for one to refer them even to their class are not numerous except in a few of the samples, and three of them (surface, 25 feet, and 550 feet) showed no determinable fragments. Foraminifera are abundant at 50 feet from the surface, and sparingly present at 75, 325, 400, 575, 625, and 675 feet. At 725 feet

they begin to abound again, and are either relatively or absolutely numerous in nearly every sample from that point to the bottom, though they are few in number at 750, 1,075, 1,225, 1,350, 1,450, 1,950, and 1,975 feet, and seem to be lacking from the samples from 775 and 875 feet below the surface. The samples from 1,625, 1,650, and 1,775 feet are especially rich in these organisms. Foraminifera of the genus *Orbitoides* seem first to appear in abundance at 900 feet from the surface. From this depth down to 1,875 feet, apparently the same species of *Orbitoides* are more or less abundant. At 1,375 feet a very steeply conical *Textularia* appears, and together with a more obtuse form is persistent to the bottom, sometimes even outnumbering the *Orbitoides*. The largest *Orbitoides* were from the depths of 1,375 and 1,400 feet and measured 3.5 and 4 mm. across.

Bits of coral are present in small numbers in about half the samples, but are not numerous enough at any depth to warrant calling the sample a "coral sand," though of course many of the undeterminable fragments may have been derived from corals. Taken as a whole, there are more bits of lamellibranch shells and casts of the interior than any thing else in the referable fragments; next to these in point of numbers come foraminifera; then follow echinoderms, corals, bryozoa, and gastropods. Below the depth of 1,425 feet foraminifera greatly predominate in the meagre recognizable remains in many of the samples. Besides the organisms just mentioned there were recognized occasionally *Dentalium*, *Cæcum*, tubes of *Spirorbis* and other annelids, spicules of *Gorgonia* and bits of what seemed to be nullipores. At 425 feet a single brachiopod (*Cistella ?*) was noted. At 300, 500, and 525 feet from the surface the thin sections showed a network of tubes reminding one strongly of the Palæozoic genus *Stromatopora*. These are referred doubtfully to the nullipores. With the exception of a few of the lamellibranchs and some of the echinoderms, minute animals are indicated by the remains. In a few cases with the lamellibranchs and the gastropods the genus and even the species could probably be determined from the fragments, and all the foraminifera could be determined or described, but the echini and corals are entirely undeterminable, and the other organisms are probably so. Many of the samples look very much like the calcareous sand forming the beach two or three miles west of Nassau, New Providence, and elsewhere in the Bahamas, judging from specimens of such sand kindly furnished the writer by Prof. R. P. Whitfield.

A condensation of the detailed record of the well as obtained from the study of the samples is as follows: —

SURFACE and 25 feet, a yellowish white, friable oölite destitute of determinable organic fragments. There is a mere trace of the angular quartz sand at the surface, but apparently none from 25 feet.

50 to 175 feet, a white, yellowish white, or very light gray, more or less compact limestone with oölitic lumps in it. Recognizable remains are mostly lamellibranchs, but the 50 foot sample is also foraminiferal. Quartz sand is lacking in the 50 foot sample, but is present in varying small amounts in the others.

200 feet. — A fine white sand-rock partly compacted and almost destitute of determinable fragments. Contains a small amount of the quartz sand.

225 to 275 feet. — A porous, white, soft, somewhat oölitic and sandy rock containing some bits of lamellibranchs, but almost nothing else recognizable. The quartz sand contains the relatively large rounded grains already mentioned. There is a comparatively large amount of it (the quartz sand) in the samples from 250 and 275 feet.

300 to 375 feet. — White, more or less solid sand-rock containing a few ovules and a little oölite and some masses of dense limestone. Very few determinable organic remains are present; among these, indications of echini are relatively numerous at 325 feet, and of lamellibranchs at 375 feet. A comparatively large amount of the angular quartz sand was observed at 300 and 325 feet, and a small amount at the other two depths.

400 to 675 feet. — A decidedly gray sand-rock, presenting a marked contrast to that above, soft and friable, but containing hard, dense, light gray limestone at 500 feet, and rather hard, porous, almost white rock, with granular calcite at 525 feet. Color seems darkest in the samples from 400 to 475 feet. The quartz sand, which is present in varying amounts, shows in some of the samples a relatively large number of the coarse rounded grains. There is a great dearth of recognizable fragments throughout this lot, and at 550 feet there seem to be none. Of the few organic remains that can be determined lamellibranchs appear to be the most numerous. A single minute brachiopod was found at 425 feet, concerning which Prof. W. H. Dall writes me: "It is either the cistella stage of a large species, or a small species of *Cistella*. I am inclined to believe it the young of a larger species."

700 to 1,075 feet. — A sand-rock varying in color from a yellowish white in the upper portions to a very light yellowish brown in the lower. The texture of the rock varies somewhat, also, being more of shell-rock at 725 feet, and a rather hard, porous rock from 750 feet to

825 feet. The remainder is more sandy, with well rounded grains, but contains some angular fragments of amorphous rock (e. g., 975 feet). All is more or less oölitic. ' The quartz sand is present only as a trace, and sometimes (975 and 1,000 feet) is scarcely perceptible. Most of the samples from these depths are notably fossiliferous, foraminifera and lamellibranchs predominating. From 900 feet down bits of madrepore corals were noted in the samples, and such fragments were rather numerous at 1,000 feet.

1,100 to 1,175 feet. — Light gray limestone, partly dense and partly porous in texture, containing only a slight trace of the quartz sand. Somewhat oölitic at 1,175 feet. Foraminifera abound, though they are somewhat less numerous in the lower than in the upper half of this set. Bits of coral, also, are more numerous in the upper half than in the lower. The fragments in the sample from 1,125 feet indicate the presence of comparatively large lamellibranchs. Remains (casts) of gastropods are more numerous at 1,150 feet and 1,175 feet than in most of the samples.

1,200 to 1,350 feet. — A gray sand-rock with the 1,200 foot sample a transition to that above, but in all the set there are many angular bits of dense and porous limestone among the rounded grains indicating the sand-rock. The quartz sand is present in all, but in the sample from 1,250 feet there is more than in any other for 350 feet above it and all the rest of the distance to the bottom of the boring. Fossils are rather scarce in this set, even foraminifera being numerous only in the three samples 1,275, 1,300, and 1,325 feet. Coral fragments come next to the foraminifera in abundance, but are very few in 1,300 to 1,350 feet. From 1,250 to 1,350 feet the rock is somewhat oölitic.

1,375 to 1,450 feet. — A yellowish gray sand-rock containing some porous limestone (much at 1,400 feet) and a little dense rock, but becoming a fine, closely compacted sand at 1,450 feet. *Textularias* of at least two species appear at 1,375 feet, and are persistent in most of the samples from this point to the bottom of the boring and outnumber the *Orbitoides* at most depths. Aside from the foraminifera very little is determinable, most of each sample except that from 1,400 feet being so finely comminuted as to pass through the No. 40 mesh sieve. Of quartz sand there seems to be none at 1,375 feet, and only a trace at the other depths. Ovules and bits of oölite are not numerous. There is some iron stain at 1,450 feet.

1,475 to 1,975 feet. — Sand-rock varying somewhat from one depth to another in color, compactness, and amount of contained dense and porous

limestone. Rounded grains are evident in the samples, and ovules and oölite occur at some depths. As to color, 1,475 feet is a decided gray, presenting a readily recognized contrast to 1,450 feet; from 1,500 feet to 1,775 feet the material is pretty uniform in color, and would be described as being light brownish gray, but dark brown spots due to iron oxide occur at 1,600 feet; 1,800 feet is light brown with many white particles (fossils, etc.); from 1,825 feet to 1,975 feet the samples are light brownish gray with a yellowish cast, or are light yellowish brown and contain more or less of the white particles. In all the samples there is a trace, or a little more, of the fine angular quartz sand, together with an occasional larger rounded grain. Determinable fragments of organisms are few in all the samples and almost absent in some. Foraminifera are by far the most abundant recognizable fossils, and they form a considerable percentage of the samples from 1,625 feet, 1,650 feet, and 1,775 feet. *Textularia* is the most numerously represented genus, with *Orbitoides* next. *Amphistegina*, *Cristellaria*, *Orbitolites*, and other genera, are also easily to be found. Other classes of organisms are not common, even lamellibranchs not being numerous except at 1,600 feet. Corals are not abundant in any of the set, and seem to be entirely lacking from many of them.

2,000 feet. — At this depth the rock loses its yellowish cast and becomes a light brownish gray, contrasting somewhat with 1,975 feet. The rock seems to have been a rather solid limestone with porous portions. It was very fossiliferous, foraminifera being especially abundant, though other classes are well represented. The obtusely and the sharply conical *Textularias* are the most numerous and *Orbitoides* seems to be absent.

Although the genus *Orbitoides* does not seem to be represented in the samples from depths above 900 feet from the surface, except sparingly at 800–850 feet, there seems to be no particular change in the rock until after 700 feet has been reached, and there is a marked transition between the sample from that depth and the one next above (675 feet). On account of these facts I am inclined to place the approximate upper limit of the Vicksburg beds of the Eocene in this well at 700 feet below the surface of the ground. The lower limit of the Vicksburg is not easily made out. *Orbitoides* seems to be the predominating foraminifer down to 1,450 feet inclusive. Between this depth and the next (1,475 feet) there is a decided change in color, and while *Orbitoides* does not disappear entirely at once, the two conical forms referred to *Textularia* are much more numerous. Below 1,875 feet *Orbitoides* seems to be lacking.

Above 700 feet the material was so comminuted, probably by the drill, that it seems impracticable to differentiate the Miocene and Pliocene beds. The surface oölite ceases between the depths of 25 and 50 feet, which may indicate that the top of the Tertiary is there. Furthermore, it seems that the marked change in the appearance of the beds between 375 and 400 feet from the surface must be of some significance.

The following notes on the samples of the borings from the Artesian well at Key West will give an idea of the condition and composition of the material examined.

SURFACE. — Color yellowish white. The surface rock consists of an oölitic limestone which pulverizes with comparative ease between the fingers. The nuclei of the ovules are for the most part rounded or subangular calcareous grains, but one ovule was observed which was built up around a grain of quartz. The matrix consists of minutely comminuted stuff. No fragments of either shells or coral were observed. The rock left the merest trace of quartz sand behind on treatment with HCl, like that which is fully described under the material from 250 feet and deeper.

25 feet. — Color yellowish white. Oölite; like the above, apparently, though the sample consisted of nothing but the ovules. Not even a trace of the quartz sand noted. After a time a flocculent brownish white precipitate settled out of the HCl solution. A flocculent precipitate like this, but varying in color to a greenish black, was obtained with almost all the samples. See Analysis, p. 85.

50 feet. — Color white with yellowish and brownish portions. A compact, somewhat sparry limestone filled with fragments of foraminifera, corals, remains of echini, lamellibranchs, gastropods, etc. Crystals of calcite are present, as is true of many of the other samples. The rock contains vast numbers of foraminifera and other calcareous micro-organisms. No quartz sand, apparently. The rock is oölitic, but is not friable like the two preceding. It is mainly a shell limestone with much oölite and foraminiferal rock.

75 feet. — Color gray-white. A compact limestone containing pieces of coral and porous lumps. Under the microscope the rock is seen to contain fragments of shells and coral in a fine granular base in which are some foraminifera. There is a very small amount of limpid quartz sand present and a heavy gray-white flocculent precipitate settles out from the HCl solution after a little time.

100 feet. — Color white. Compact limestone containing abundant remains of corals and shells, pectinoids, and other lamellibranchs. Some of the shell fragments are in a matrix of oölite. Very, very small amount of quartz sand. Much of the flocculent precipitate in HCl. The lamellibranchs predominate among the determinable remains.

125 feet. — Color white with brownish white portions. The sample is of an almost pure white rock, but it contains a fragment of limestone like the preceding, cracks in which have been filled with secondary calcite. It is a very porous rock for the most part. There are a few casts (or imprints) of parts of corals present. Consists of fragments of shells (lamellibranchs) and many ovules in a matrix of amorphous or unrecognizable material. Sometimes the shells have leached out leaving the rock porous. Part of the sample is a true oölite, some of which is friable and some has been cemented by calcite to form a firm rock. The sample contains internal casts of lamellibranchs and fragments of their shells. A very small amount of limpid quartz sand is present.

150 feet. — Color yellowish white. A trace of quartz sand is left on dissolving the rock in HCl. The rock seems to have been a hard, compact limestone. Observed fragments of shells and internal casts of lamellibranchs and a few pieces of coral; many rounded grains, but very little true oölite. Most of the recognizable organic remains are of lamellibranchs. There are many facetted fragments which seem not to have been made by the drill, but to be the remains of the internal pillars of sea-urchin tests. There are many angular bits of stone which is as dense and crystalline as marble.

175 feet. — Color white. A limestone like the last, except that it seems as if a larger proportion of it were porous and a smaller proportion determinable. A small amount of quartz sand is present. Lamellibranchs predominate among the remains that are determinable.

200 feet. — Color yellowish with many pure white particles (bleached organisms). This sample consists almost entirely of a fine uncompacted calcareous sand in which there is a very small amount of limpid quartz sand. The particles of the sand have been weakly cemented in places. A few chips indicate the presence of some compact rock. The grains are rounded and subangular. Ovules were noted but are scarce. The fragments were almost all undeterminable, but in the small portion of the sample which failed to pass through a No. 40 mesh sieve there were a few pieces of madrepore corals, some indications of echini, fragments of both branching and incrusting bryozoa, bits of lamellibranch shells, and casts of minute gastropods.

225 feet. — Color white with very slight yellowish tinge. Sample contains a small amount of fine angular quartz sand; coarser grains of quarts were rounded. Rock was a rather porous limestone with areas of granular calcite. Partly oölitic. There were but few determinable organic remains in the sample. A very few bits of coral, spines of echini, and fragments of branching bryozoa were noted. Many fragments of lamellibranch shells and casts (*Arca? Pecten?* etc.), and a very few internal casts of minute gastropods.

250 feet. — Color white. Sample consists of rounded and subangular grains. Rock was a soft, porous, and granular limestone. A considerable percentage of very fine-grained limpid quartz sand is present, the particles of which are angular or but slightly rounded. No definitely terminated crystals were observed, though some of the surfaces suggested the rhombohedral planes in shape and position. By far the largest part of this quartz sand is very minute in size,

but an occasional particle of larger size, even up to a millimeter in diameter, occurs. These larger grains are well rounded and somewhat rough on the exterior, rendering them less transparent. The quartz particles are recognizable with an ordinary lens. No recognizable fragments of organisms were noted, except a very few of lamellibranch shells. A very little oölitic material was noted.

275 feet. — Color white. This rock is more compact than the last, and may be described as a rather solid lime sandstone. (I use this term as meaning a lime rock in which the individual grains of calcareous sand are readily discernible. It would bear somewhat the same relation to compact limestone that ordinary siliceous sandstone does to quartzite.) Some fragments in the sample are of compact limestone. The amount of limpid quartz sand is larger than in the last sample. Recognizable organic remains are very scarce. Noted, however, one or two pieces of coral, a few bits of bryozoa, and a good many more of lamellibranch shells and casts.

300 feet. — Color white. This is a sand-rock containing some portions of dense limestone and a small percentage of oölite. Very few determinable organic remains were observed. Noted a few bits of millepores, a few fragments of bryozoa, coral doubtful, pieces of lamellibranch shells of several genera, and a very few internal casts of minute gastropods. A very noticeable proportion of the limpid quartz sand is present. Some measurements of grains gave diameters of 0.12 mm. and 0.1 mm. as average, with an occasional larger particle, one of which was 0.55 mm. across. The mass of the rock is made up of white calcareous sand cemented together too firmly to be crushed between the fingers. There are a few ovules. These are easily distinguished by their regular form and smooth exterior. A thin section made from a hard lump shows a structure comparable with that of a Palæozoic *Stromatopora*. The cells are too irregular to be those of a millepore and the reticulate structure may be due to anchylosed branches of a nullipore. (A similar organism from 500 feet shows that these apparently solid branches are tubes.)

325 feet. — Color a yellowish gray-white. Limpid quartz sand, as in last three samples. The sample is made up almost wholly of fine, angular calcareous sand, but there are some lumps. It was a sand-rock. Ovules are scarce but present. Very few fragments are determinable. Some are apparently nullipores. Spines and plates of echinoid tests are relatively numerous. Branching bryozoa not rare. Some few bits of lamellibranch shells. Very, very few remains (casts) of gastropods, one of which is a comparatively large trochoid shell. Annelid tubes in groups and singly. Found several (half a dozen or so) foraminifera. The single annelid tubes are strongly curved and may be *Spirorbis*.

350 feet. — Color a yellowish gray-white. Small quantity of the quartz sand present. One fragment, at least, seems to show the terminal crystal planes. A few considerable fragments of coral are in the sample, and fragments (spines and pieces of test) of echini and lamellibranchs. One piece is apparently part of a group of annelid tubes. No ovules observed. The rock

was a comparatively coarse white sand-rock with very few determinable organic remains in it.

375 feet. — Color yellow gray-white. A sand-rock with many coarse particles in it. The fine angular quartz sand is present in very small amount, with an occasional much coarser particle which is well rounded on account of abrasion. Very, very little of the material is determinable. I noted a few small bits of coral and more fragments of lamellibranchs, three or four spines of echini, and as many pieces of annelid tubes. Some ovules are present. The coarser particles of the general sample are angular bits of dense white limestone.

400 feet. — Color a decided gray, in marked contrast with the white rock of the preceding samples. The rock was a rather loosely compacted sand-rock, containing some porous, hard, white fossiliferous portions. A few bits of oölite and some single ovules were noted, also white. The limpid angular quartz sand is present in noticeable proportion. It is very fine and uniform in grain. One foraminifer, two or three kinds of coral, some fragments of bryozoa, more lamellibranchs, part of the internal cast of a gastropod, portions of annelid tubes, and bits of nullipores (?) were observed among the meagre determinable organic remains.

425 feet. — Color decided gray. The fossils are white. The gray sand-rock which makes up more than nine tenths of the sample seems to contain very few fossils; these are mostly to be found in the hard, dense, and porous white masses which are scattered through the gray. The quartz is present in comparatively large proportion, mostly very fine grained and angular, but with an occasional more or less rounded particle. One of the last measured 1.5 × 1 mm. Determinable organic remains are scarce, as usual, and are for the most part of lamellibranchs (shells, casts, and imprints). Noted also a few bits of coral and a few fragments of echini (spines, tests, and internal facetted supporting pillars), and part of the frond of a bryozoan. Small oölite aggregates are not uncommon. A single minute brachiopod was found, concerning which Prof. W. H. Dall writes me, "It is either the cistella stage of a large species, or a small species of *Cistella*. I am inclined to believe it the young of a larger species."

450 feet. — General color and character of sample are like the last. The rock consists of loosely compacted, very fine grained calcareous sand, with occasional lumps of hard white limestone. The limpid quartz sand is present in very small amount, but with the same characteristics as before. Measurements of some of the grains were 0.1 mm., 1.5 mm., 0.09 mm., and 0.11 mm. in diameter. Angular pieces of secondary calcite as in many of the samples. Some bits of oölite observed. Internal casts of lamellibranchs rare. Fewer of the angular fragments of solid limestone present than in the last two samples, and almost nothing is determinable.

475 feet. — Color decided gray, more uniform in color and texture than the three above. This is a lime sand-rock, somewhat friable, like the last three samples, except that it contains fewer fragments of solid limestone than even

the last, and next to nothing is determinable. Small amount of the limpid quartz sand with the usual features. Fragments of a bryozoan and a very few lamellibranchs and echini noted. The sample includes lumps of firm white oölite.

500 feet. — Color decided gray, with white fossils and pearl-gray limestone. Sand-rock, rather friable but with hard lumps. Contains some fossils, which are white, and some white aggregations, as well as fragments of compact gray limestone. Occasional small lumps of white oölite are present. Quartz sand present in small amount as before. Pieces of compact gray limestone show, in the thin section, the stromatoporoid structure noted at 300 feet and doubtfully referred to a nullipore. This is made up of branching, anchylosed tubes solidified by calcite. Fragments of lamellibranchs, one of them a *Corbula*, another an *Arca* (?) ; spines and other parts of echini. A nearly entire spine had been perforated lengthwise by a boring lamellibranch now in it. Bits of coral are not rare. There are also a few fragments of bryozoa. Gastropod remains are very scarce. Saw part of internal cast of one minute one.

525 feet. — Color decided gray, with white lumps and yellow-white fossils. A very friable sand-rock containing masses of hard white porous rock and white fossils and calcite. Much like preceding in color, amount of quartz sand, etc. It is composed of loosely compacted, very fine calcareous sand, with few solid fragments and almost nothing recognizable. A piece of porous limestone shows moulds of lamellibranch shells, spines of echini, etc. There is also a piece showing the " stromatoporoid " structure, like those in the material from 300 feet and 500 feet. Some oölite; secondary calcite, of course. Some indications of coral.

550 feet. — Color decided gray, like 475. A very friable sand-rock, very uniform in color and texture. Almost no bits of white. The small amount of quartz sand present is relatively coarse in grain. Remarkably destitute of determinable fragments, recognized none in fact.

575 feet. — Color decided gray, like 475. A friable sand-rock like the last except that it contains some recognizable fragments. Small amount of the quartz sand present. Some ovules and an occasional small piece of oölite present. Sample mostly a very fine sand, more than two thirds of it going through a No. 40 mesh sieve. Fragments of lamellibranch shells, one minute gastropod, three or four bits of bryozoa, and one piece of coral recognized. A few foraminifera of the genus *Amphistegina* were noted.

600 feet. — Color decided gray, like 475, but lighter shade. A friable sand-rock containing much white material which is mostly crystalline limestone or granular calcite. Quartz sand in small amount as before, very fine grained, angular, no large particles. A few ovules are present and some fragments of lamellibranchs together with the facetted fragments. More than three fourths of the sample went through the sieve, much of the fine stuff being mere dust. Almost nothing determinable.

625 feet. — Color gray, like 600. A very friable sand-rock, but with less white material in it and therefore darker colored as a whole. Limpid quartz

same as last. The sample consists of uncompacted fine calcareous sand, with few large fragments in it. The facetted fragments, a few pieces of lamellibranch shells, and a branch of a calcareous alga (?) were noted. Some few ovules. Part of a spine of an echinus. The test of a foraminifer of the genus *Cristellaria* (?). Almost nothing is determinable.

650 feet. — Color gray, like 600. A very friable sand-rock, like the last. Limpid quartz is very small in amount, and seems to be of finer grain than the average. Spines of echini, lamellibranch shells, an alga (?), and pieces of oölite were noted. Almost nothing is determinable

675 feet. — Gray, like 600, possibly a little darker. A very friable sand-rock. Quartz like the last, but with more of the larger rounded grains. Small pieces of oölite, lamellibranch shells, spines of echini, and tests of foraminifera noticed. One of the last looked like an *Orbitolites* and another like a *Clavulina*. As in the preceding five, there is a great dearth of referable fossil remains.

700 feet. — Color yellowish gray-white, very different from 675 and above. Marked change in the rock. Sample is a very fine uncompacted sand, almost all of which passed through the No. 40 mesh sieve. Amount of quartz sand has dropped off considerably. The quartz grains are more varied in size than has been usual. Fragments of lamellibranch shells and spines of echini, small pieces of oölite, and many detached ovules are present. Almost nothing is determinable. The whole sample looks like a fine beach sand.

725 feet. — Yellowish white (ecru) limestone, mostly a "shell rock." Amount of quartz reduced to a trace. Many relatively large fragments of lamellibranch shells are present, some of which are recognizable as *Pectens* or closely related shells. A very few minute gastropods. Spines of echini and pieces of their tests, many ovules and some pieces of oölite observed, bryozoa, and foraminifera (*Amphistegina ? Orbitolites ?* etc.) are numerous. A considerable proportion of the sample is of determinable fragments. A globular foraminifer appears and is relatively abundant.

750 feet. — Color yellowish white (ecru). Very small amount of quartz sand. Fragments and internal casts of lamellibranchs, — pectinoids, etc. Parts of internal casts of minute gastropods. Fragments of tests of echini. *Orbitolites* (?) and other foraminifera. Ovules but no oölite observed. Some bryozoa. A few fragments of corallines (?).

775 feet. — Color very light yellowish brown. A hard, rather porous, highly fossiliferous limestone. Trace of the quartz sand very fine. Many shells and casts of pectinoids and other (small) lamellibranchs. Small gastropods. Spines and plates of echini. Ovules present in small numbers. There are considerable fragments ($\frac{3}{8}'' \times \frac{3}{8}'' \times \frac{3}{4}''$) present, but no coral was observed. Foraminifera are very scarce, if present at all none were observed.

800 feet. — Very light yellowish brown, like the last. Amount of quartz sand small, but greater than in any of the last four samples. The rock seems to have been a rather hard, very porous limestone. Ovules rather numerous. Foraminifera (*Orbitolites ? Cristellaria ? Amphistegina ?* etc.) in numbers. A

very few discoid *Orbitoides* are present. Shells and casts of lamellibranchs numerous. Casts of gastropods. Spines and plates of echini. Some fragments of shells show the effects of boring organisms. Some bryozoa, both branching and incrusting.

825 feet. — Color very light yellowish brown. Sample is finer grained than the last. Small amount of quartz sand, one rounded particle of which measured more than .5 mm. in length. Ovules present in considerable numbers. In this and other cases the concentric structure is evident when the ovule is broken across. The rock seems to have been somewhat compacted. More secondary calcite than usual. Many shells and casts of lamellibranchs and few of gastropods. Spines of echini and the facetted fragments. Annelid? tubes. Foraminifera. Bryozoa. Some spicules of *Gorgonia*. A very few fragments of discoid *Orbitoides*.

850 feet. — Color very light yellowish brown. Sample is a fine sand, nine tenths of which passed through the No. 40 mesh sieve. Trace of the quartz sand. Foraminifera of several genera abound. Some small fragments of coral. Branching and incrusting bryozoa of several genera were observed. Many shells and casts of minute lamellibranchs. Internal casts of very small gastropods. Spicules of *Gorgonias* numerous. Ovules also frequent. Spines of echini. *Orbitoides?* very scarce, but *Cristellaria? Amphistegina? Orbitolites?* etc., numerous.

875 feet. — Color very light yellowish brown, like the last. Mere trace of the quartz sand. Sample is meagre in determinable organisms. Ovules not very numerous. Spicules of *Gorgonia*, spines of echini, and remains of lamellibranchs are present. Some pieces of brown granular calcite. *Orbitoides* not observed.

900 feet. — Color, very light yellowish brown. Trace of quartz sand as in last. A few small fragments of loosely compacted rock. Foraminifera of several genera. *Orbitoides* in numbers appear. Some small bits of madrepore and other coral. Many shells and casts of small lamellibranchs. Gastropods not definitely recognized. Fragments of tests of echini. Nullipores? Spicules of *Gorgonias*. Ovules not very numerous. Some bits of brown granular calcite.

925 feet. — Color very light yellowish brown. Many white particles. Faint trace of quartz sand. Ovules not numerous, but there are some pieces of oölite. Foraminifera abound among which *Orbitoides* are very numerous. Some few fragments of madrepore coral. Bits of echini occur, and one little fragment suggests the arm of an astrophyton. Remains of lamellibranchs are common, but those of gastropods are rare. Spicules of *Gorgonias* in numbers. Bryozoa not rare. Most of the determinable fragments are foraminifera. The whole sample looks like a moderately coarse beach sand rather than crushed rock.

950 feet. — Color light yellowish brown. Texture same as preceding. Faint trace of quartz sand. The sample is a loose fine sand in which ovules are numerous. Foraminifera (*Orbitoides*, etc.) abound. Bits of madrepore coral

not rare, — more numerous than heretofore. Remains of echini unusually scarce. Bryozoa scarce, but include branching and incrusting forms. Remains of lamellibranchs rather numerous, but few gastropods recognized. Spicules of *Gorgonias*. Proportion of recognizable remains seems rather less than in the last.

975 feet. — Color very light yellow brown. Sample shows more evidence of being comminuted rock. Quartz sand scarcely perceptible. Ovules occasional, and rounded grains very numerous. Foraminifera (*Orbitoides* and others) abundant. A few pieces of coral were noted. Bits of echini occur, and facetted fragments are numerous. Bryozoa not observed. Remains of lamellibranchs numerous, but those of gastropods scarce. Seems to have been a loosely compacted, rather coarse sand-rock.

1,000 feet. — Color light yellowish brown. Quartz sand scarcely perceptible. The sample contains a considerable proportion of coarse sand and fragments. Ovules not noted, though rounded grains are numerous. Foraminifera of several genera abundant, — *Amphistegina*, *Orbitoides*, the globular one, etc. Bits of madrepore coral frequent. Annelid tubes and *Serpula* (?) or *Vermetus* (?). Fragments of tests of echini (*Spatangus* ?). Lamellibranchs as usual, and gastropods not uncommon; of the latter, *Turritella*, *Natica ? Cæcum*, and *Dentalium* were recognized. Bryozoa present. Spicules of *Gorgonia*.

1,025 feet. — Color very light yellow-brown. Trace of quartz sand. Sample is fine calcareous sand with the coarser remains of organisms. Ovules not noted, but rounded grains are common. Foraminifera very abundant. Small bits of madrepore coral not infrequent. Both branching and incrusting bryozoa. Lamellibranch remains as usual. *Cæcum* and *Dentalium* observed, and other minute gastropods frequent.

1,050 feet. — Color very light yellow-brown. Trace of quartz sand. No ovules noted. Foraminifera form the principal constituent of the coarse part of the calcareous sand. A few pieces of coral. Bryozoa as in last. Remains of lamellibranchs common, but gastropods scarce.

1,075 feet. — Color very light yellowish brown. Trace of quartz sand stronger than in last. The sample is a very fine sand, with only a few fragments in it too coarse to go through the sieve. In the residue there were foraminifera, a few bits of coral, a single spine of an echinus, some bryozoans, and more lamellibranch remains. Ovules are present in the sample, but very scarce.

1,100 feet. — Color light brownish gray. Trace of quartz sand. The sample is a fine uncompacted calcareous sand, containing a much larger proportion of coarse particles and fragments than the last. Ovules seem to be absent. Foraminifera of several genera are numerous. Bits of madrepore corals are very numerous. Bryozoa of both branching and incrusting forms are not rare. Lamellibranch shells and casts are present in abundance, but gastropods are scarce. I noticed a few spines of echini also, and some of the facetted fragments described in the earlier part of these notes.

1,125 feet. — Color light brownish gray. Very slight trace of quartz sand.

The sample is a coarse calcareous sand (gravel it might be called) with many recognizable fragments in it, and not much of it passed through the sieve. Some pieces of compact limestone. No ovules were observed. Foraminifera not as numerous as in last. Bits of madrepores very numerous. Spines and plates of echini are scarce. Bryozoa are common, and lamellibranch remains are very abundant. A few of the fragments indicate that some of the lamellibranchs were quite large. A few gastropods were noted.

1,150 feet. — Color light brownish gray. Very slight trace of the quartz sand. The sample is a coarse calcareous gravel (comminuted rock) like the last. Foraminifera of several genera are numerous. Bits of madrepores are common. Some spines and plates of echini were observed. Lamellibranch remains very numerous. Gastropod shells not uncommon, and some genera noted not seen before. Ovules appear to be absent.

1,175 feet. — Color light brownish gray, like that of preceding. Very slight trace of the quartz sand. The sample consists largely of comminuted rock, but there are many rounded sand grains in it and a very few ovules; the latter were determined by their concentric structure. Foraminifera are numerous, but bits of coral (madrepores) are less abundant. A few spines and plates of echini were noted. Bryozoa numerous. Lamellibranchs are very abundant. Gastropods more common than usual.

1,200 feet. — Color light brownish gray. The limpid quartz sand is present as usual in very small amount. Sample seems to be a very finely comminuted rock, as it is made up for the most part of angular fragments. It is much finer grained than the last two, and there are fewer determinable fragments. No ovules. Foraminifera are common, and minute bits of coral (?) abound. Remains of echini are very scarce. Bryozoa rather common. Lamellibranch remains are very numerous, but there are very few gastropods.

1,225 feet. — Very light brownish gray. The quartz sand is present as a mere trace. The same is a very fine calcareous sand, most of the grains of which are rounded. No ovules. More than nine tenths passed through the sieve, and the rest is not very coarse. There are a few angular bits of limestone in the residue. Not much is determinable, but I noted a few foraminifera, many fragments of coral, some lamellibranchs, and a few gastropods (?).

1,250 feet. — Color very light brownish gray with many white particles. The amount of quartz sand is greater than it has been for 350 feet. The sample consists of a very fine grained calcareous sand, with comparatively few coarse particles in it, but in the latter are some angular bits of rock. Among the coarser particles are many foraminifera and bits of coral. Echini not noted. Bryozoa doubtfully recognized. Lamellibranchs, as well as gastropods, seem to be scarce. Some ovules and a few small bits of oölite were observed.

1,275 feet. — Color light brownish gray. Quartz sand present in small amount. The percentage of coarser material is greater than in the last two, and one can see in it bits of porous as well as compact limestone. Sample, aside from organic remains, consists largely of rounded grains. Ovules were observed, but they are very scarce (and may have come from 1,250 feet ?).

There are many foraminifera, and bits of coral are numerous. A few spines of echini were noted, and also a few bryozoa. Lamellibranchs are not numerous, and gastropods are very rare.

1,300 feet. — Color light brownish gray. Trace of quartz sand present. In the coarse portion of the sample there are many bits of porous rock, some of compact, and a few of oölitic. Much of the finer stuff is rounded. Some ovules. Foraminifera abound, and the curiously distorted *Orbitoides* have reappeared. Bits of coral are not uncommon, but there are very few remains of echini and bryozoa present. Lamellibranch remains are common, and gastropods are scarce. Noted some annelid (?) tubes. As usual, however, most of the material is unrecognizable.

1,325 feet. — Color light brownish gray. Almost no quartz sand, but an occasional particle may be noted in the fine stuff. Four fifths of the sample went through the No. 40 sieve. Originally a porous sand-rock? Ovules are rather numerous. Many foraminifera were noted, some of different genera than any heretofore observed. Bits of coral not uncommon. Echini seem to be absent. There are a few bryozoa. Lamellibranchs are common, but gastropods rare, as usual.

1,350 feet. — Color light brownish gray. Quartz sand very small in amount, but of same character as before. Comparatively little of the sample went through the sieve. The residue shows that the rock was very porous, and contained many rounded grains of sand and some ovules. The rock also contained some nodules of compact limestone. It appears to be different from the 1,325 foot sample. Determinable organic remains were not very abundant, but I noted foraminifera (*Orbitolites*, etc.), coral (?), two or three spines of echini, and a few bits of bryozoa. Gastropods (*Dentalium*, etc.) were scarce, and lamellibranchs not numerous.

1,375 feet. — Color light brownish gray, with yellow cast. The quartz sand seems to be wanting. At least nine tenths of the sample went through the sieve as a rounded sand. In the residue are some bits of friable porous rock, and a few of compact stone, as if of nodules. Ovules (?) are present. Foraminifera are numerous, and some *Orbitoides* are large, one measuring 3.5 mm. across. *Textularia* appears. Several fragments of madrepores were noted. Spines of echini and the facetted bits are few in number, and so too are bryozoan, lamellibranch, and gastropod remains.

1,400 feet. — Very light brownish gray. Of quartz sand there is but a trace. The rock seems to have been a very porous limestone, and coarse, loosely compacted sand-rock containing nodules of solid limestone. Some ovules and a few bits of oölite were noted. Foraminifera are numerous, and some (*Orbitoides*) are as much as 4 mm. in diameter. The *Textularias* are common. Many bits of madrepore coral. A few spines and plates of echini. Bryozoa are very rare, and gastropods, and even lamellibranchs, are not common. The proportion of coarse material and determinable fragments is large.

1,425 feet. — Color very light yellowish brown. Quartz sand a mere trace, but the grains can be distinguished readily under the microscope, as is the case

in all the samples where it is present at all. Originally was a loosely compacted fine-grained sand-rock with some solid limestone in it. Not much is recognizable. In the small determinable component were seen foraminifera (*Textularia*, *Orbitoides*, *Cristellaria*, *Orbitolites*, etc.), a few spines of echini, some remains of lamellibranchs (one is part of a comparatively large shell). It is doubtful whether any gastropods are present.

1,450 feet. — Color very light yellowish brown, with deep brown spots colored by limonite. The quartz sand is present as a mere trace. The rock seems to have been a very loosely compacted sand-rock, with a very few lumps and no solid limestone in it. The grains are rounded, and there are some ovules and bits of oölite in the material. Almost all the sample went through the sieve, and is too fine to be determinable. In the small residue were noted some foraminifera, an occasional bit of coral, and a few remains of lamellibranchs.

1,475 feet. — The color has changed decidedly to a pure light gray. A few angular particles of limpid quartz were noted. Scarcely one per cent failed to pass the sieve, and very little of this residue is determinable. As usual, most of the recognizable forms are foraminifera (sharply and obtusely pointed conical *Textularia*, *Cristellaria*, *Biloculina*, etc.). There are also bits of madrepore corals, millepores (?), branching bryozoans, and of lamellibranch shells and casts. The sample seems to be a very fine sand, without lumps or chips of solid rock.

1,500 feet. — Color light brownish gray. Quartz sand, — a mere trace. Sample is a very fine calcareous sand with a very few angular bits of rock in it. The sand consists of rounded and subangular particles. No ovules or oölite noted. Of the recognizable forms most were foraminifera, some of which were large (*Orbitoides*, *Textularia*, etc.). Some bits of coral and a very few spines of echini. Fragments of branching bryozoans were noted, and a few remains of lamellibranchs. Nothing could be determined even generically except the foraminifera.

1,525 feet. — Color light brownish gray, like the preceding. Quartz sand likewise a trace, — visible under the microscope and left as residue by HCl. Mostly a very fine sand, but in the coarser part are some relatively large pieces of a porous sand-rock, consisting of rounded grains with an occasional fossil. Organisms recognized: many foraminifera of several genera, the conical *Textularia* being the most common; a few bits of coral and branching bryozoans; lamellibranchs scarce and gastropods very scarce, but probably present.

1,550 feet. — Color light brownish gray. Quartz sand, — a mere trace, as usual. Appears to have been a porous limestone and sand-rock, none of which was solidly compacted. Foraminifera are very numerous, *Textularia* predominating. A few bits are doubtfully referred to madrepore coral. Remains of echini, branching bryozoa, lamellibranchs, and gastropods were noted, the last being very scarce.

1,575 feet. — Color light brownish gray, like the last. The angular limpid quartz sand is present as a mere trace. Seems to have been a moderately coarse sand-rock with much fine material in it, the grains are rounded, and

there are some ovules present. A very few remains of echini, bryozoa, lamellibranchs and gastropods were observed, also *Textularia* in numbers, *Amphistegina*, etc., among foraminifera.

1,600 feet. — Color light brownish gray, with deep brown spots of limonite. Trace of quartz sand. A sand-rock containing lumps of compact limestone, as well as porous material not sand-rock. The determinable material was mostly foraminifera of several genera. There were also a few bits of madrepore corals, echinus spines, and branching bryozoa. Many remains of lamellibranchs and a few casts of gastropods. One piece of *Dentalium* was observed.

1,625 feet. — Color light brownish gray. The limpid quartz sand present as a slight trace. Again a rather loosely compacted coarse sand-rock with much very fine material in it. Contains some lumps of solid limestone and alse porous rock. Foraminifera very numerous and well preserved, the conical *Textularia* being especially abundant. Bits of coral, spines and plates of echini, and fragments of branching bryozoa are few. Pieces of lamellibranch shells are scarce, and casts of gastropods are very rare. Noted an occasional *Dentalium*.

1,650 feet. — Color light brownish gray. Trace of the quartz sand. The sample is very much like the last, with perhaps rather more chips of solid limestone in it. As usual foraminifera form a very considerable portion of the determinable remains. No bits of madrepore corals were noted. Spines and plates of echini are not scarce; some bryozoa are present; lamellibranch and gastropod remains are rare.

1,675 feet. — Color light brownish gray. Trace of the quartz sand. Sample appears very much like the last, but with fewer bits of solid and porous rock in it. It was mainly a sand-rock. Proportion of determinable remains smaller, perhaps, than in the last. Foraminifera of the usual genera abound; spines of echini are not rare; bryozoa, lamellibranchs, and gastropods occur very sparingly.

1,700 feet. — Color light brownish gray. Quartz sand rather more abundant than in the last three samples. The sample contains almost no angular fragments, and seems originally to have been a fine sand-rock. A few ovules? The proportion of determinable remains is very small. Foraminifera (*Textularia*, *Orbitolites*, etc.) are most numerous among them. Some spines of echini and bits of branching bryozoa were noted. Lamellibranch remains are unusually scarce and gastropods seem to be absent.

1,725 feet. — Color light brownish gray. A very small amount of the extremely fine quartz sand, in which is an occasional larger and more rounded grain. The rock seems to have been a moderately coarse sand-rock with much fine material in it, and the grains were rounded. A few ovules (?) were noted. Foraminifera of apparently the same genera as heretofore abound. Some fragments are doubtfully referred to coral. Spines of echini are comparatively numerous, and so too are branching bryozoa. Lamellibranchs are scarce and gastropods seem to be absent.

1,750 feet. — Color light brownish gray. Slight trace of quartz sand. This

seems to be another rather coarse sand-rock with somewhat less fine material than the last, but containing also some solid and some porous limestone. A few ovules? Foraminifera abound, especially the textularias. A few fragments seem to be bits of madrepores. Spines (and plates) of echini are comparatively numerous. Some bryozoa are present, but lamellibranch remains are very scarce and gastropods seem to be absent.

1,775 feet. — Color light brownish gray. A very few particles of the angular quartz sand. Seems to have been a moderately coarse sand-rock like the preceding, but with very few bits of either solid or porous limestone. There seem to be a few ovules. Foraminifera of the several genera already noted are very abundant. Spines and plates of echini are comparatively numerous (perhaps some are from starfish). Some remains of lamellibranchs and a few minute gastropods were observed.

1,800 feet. — Color light brown with white particles. Trace of the quartz sand. The sample consists of a fine calcareous sand more than nine tenths of which passed through the No. 40 mesh sieve, and there are no very coarse particles in the residue, though there are a few small angular chips of solid limestone. Some ovules? Not much is determinable, but most of what is consists of foraminifera. Noted also a few spines of echini, some branching bryozoa, and a very few fragments of lamellibranchs. Gastropods seem to be absent.

1,825 feet. — Color light brownish gray with yellowish cast. Trace of the quartz sand. The sample is a fine calcareous sand, three fourths of which passed through the sieve. Some small angular bits of solid limestone appear in the coarser portion. Among the determinable forms foraminifera abound and the *Textularias* are the most numerous of these. *Orbitoides* also. There are also some spines of echini, a few bryozoa and lamellibranchs, and possibly a very few gastropods.

1,850 feet. — Color light brownish gray with yellowish cast, like the preceding. Quartz sand, a trace. The sample is a calcareous sand like the last, except that the proportion of coarser particles is rather greater. Organic contents like those of the last; mostly foraminifera of the usual genera with a few spines of sea-urchins, bryozoa, bits of lamellibranch shells and a very few gastropods. The *Textularias* predominate among the foraminifera. Among the coarser particles are some bits (or masses) of rather densely compacted sand-rock, and some angular bits of solid limestone.

1,875 feet. — Color light yellowish brown with many white particles. Trace of quartz sand. The sample is for the most part a very fine calcareous sand, nine tenths of which passed through the sieve. In the residue were some very angular bits of dense and porous rock and oölite. Loose ovules are not uncommon in the sand. Among the numerous foraminifera are some very large *Textularias*, *Orbitoides*, etc. A very few fragments look like madrepores. Spines and plates of echini are not rare. Bryozoa are scarce. There are a few remains of lamellibranchs and fewer of gastropods. One of the last is the internal cast of a purpuroid shell, possibly a *Pseudoliva*, about 3 mm. high. As usual, nearly all the sample consists of rounded, undeterminable grains.

1,900 feet. — Color light yellowish brown, with many white particles, like the preceding, but the amount of residue on sifting is even less than with that. A mere trace of the quartz sand is present. It is angular and limpid as usual. The sand may have been compacted to some extent, and there were some masses or layers of dense material in it, as is shown by some angular fragments. Some few ovules. Organic remains consist mostly of foraminifera. There are besides a very few bits of madrepores, some spines of echini, and a few bryozoa. Remains of lamellibranchs are few and of gastropods still fewer. Some rings look like parts of calcareous algæ, while others are portions of burrows and worm (?) tubes.

1,925 feet. — Color yellowish brown, white spots. Trace of the quartz sand, but it seems to be rather more than in the last. The sample is a very fine sand, very little (about 5% ?) failed to pass the sieve. Some ovules present, This sand also appears to have been compacted to some extent, or to have had compact lumps, and there are some angular fragments of dense limestone in the material. Determinable organic remains are few. There are mostly foraminifera of the usual genera. With these are some bits of madrepores (?), spines of echini, and bryozoa. Lamellibranch remains are rare, and those of gastropods were not observed. Some nullipores.

1,950 feet. — Color light yellowish brown. Quartz sand present in a very, very few particles of the finest grain (angular). Not more than two per cent of the sample failed to pass through the sieve. There were some lumps to indicate that the sand had been compacted to some extent. Some ovules. There were also a few angular bits of dense limestone containing organic remains. Very, very little of the sample is determinable. There are a few large foraminifera and some small ones. The large forms are *Textularia*. Some spines of echini were noted, and some pieces that were probably bryozoa. There were a very few remains of lamellibranchs, but none of gastropods were recognized.

1,975 feet. — Color light yellowish brown, with many white spots. Quartz sand, a mere trace. The sample is a very fine calcareous sand, like the last, with perhaps more compacted sand-rock in it. As before, there are a few angular bits or chips of dense limestone. In regard to organic remains it is like the last.

2,000 feet. — The color has changed to a light brownish gray. Quartz sand, a slight trace, an occasional particle of which is rounded and is too large to go through the sieve. Less than half the sample went through the sieve. The rock seems to have been a rather solid, very fossiliferous limestone. Foraminifera are very abundant, and of more than the usual genera, low conical and high conical *Textularias* predominating. Bits of madrepore corals present in small numbers. Spines, plates, and larger fragments of sea-urchin tests are not uncommon. Several fragments of branching bryozoa were observed, and a few pieces of lamellibranch shells and casts, as well as a very few casts of minute gastropods.

Analyses of Artesian Well Borings, Key West, Florida.[1]

<table>
<tr><th></th><th>25 ft.</th><th>100 ft.</th><th>150 ft.</th><th>350 ft.</th><th>600 ft.</th><th>775 ft.</th><th>1,125 ft.</th></tr>
<tr><td>SiO_2</td><td>.17</td><td>.25</td><td>.12</td><td>3.52</td><td>5.10</td><td>.13</td><td>.05</td></tr>
<tr><td>Al_2O_3</td><td>.20</td><td>.17</td><td rowspan="2">.08</td><td rowspan="2">.40</td><td rowspan="2">.35</td><td rowspan="2">.14</td><td rowspan="2">.21</td></tr>
<tr><td>Fe_2O_3</td><td>.07</td><td>.07</td></tr>
<tr><td>CaO</td><td>54.03</td><td>54.01</td><td>54.38</td><td>51.46</td><td>48 87</td><td>46.53</td><td>53.84</td></tr>
<tr><td>MgO</td><td>.29</td><td>.77</td><td>.86</td><td>1.67</td><td>2.50</td><td>6.70</td><td>.86</td></tr>
<tr><td>CO_2</td><td>42.52</td><td>42.84</td><td>43.36</td><td>41.77</td><td>40.72</td><td>43.60</td><td>42.87</td></tr>
<tr><td></td><td>97.28</td><td>98.11</td><td>98.80</td><td>98.82</td><td>97.54</td><td>97.10</td><td>97.83</td></tr>
</table>

	1,325 ft.	1,400 ft.	1,475 ft.	1,625 ft.	1,850 ft.	2,000 ft.
SiO_2	.07	.19	.06	.05	.03	.07
Al_2O_3, Fe_2O_3	.11	.16	.14	.17	.17	.16
CaO	54.49	55.12	54.48	53.90	54.28	54.02
MgO	.62	.30	.73	1.14	1.12	1.06
CO_2	43.29	43.28	43.38	43.37	43.13	43.20
	98.58	99.05	98.79	98.63	98.73	98.51

All the above samples contain more or less P_2O_5. This, together with any TiO_2 that may be present, shows as Al_2O_3 above.

[1] By George Steiger. F. W. Clarke, Chief Chemist.

Record of the Artesian Well at Key West, Florida.

Depth.	Color.	Texture.	Quartz Sand.	Foram.	Corals	Echin.
Surface.	Yel. wh.	Oölite.	Merest trace.	. . . .	. . . .	. . .
25	Yel. wh.	Oölite.	None.	. . . .	. . . .	. . .
50	White.	Compact, with some oölite.	None.	*	+	+
75	Lt. gray.	Partly compact and partly porous.	A small amt.	+	+	. . .
100	White.	Compact, with some oölite.	Trace.	. . . .	+	. . .
125	White.	Porous, with compact portions.	A small amt.	. . . .	+	. . .
150	Yel. wh.	Compact and hard.	Trace.	. . . .	+	+
175	White.	Compact, w. porous portions.	A small amt.	. . . .	+	+
200	White.	Fine sand rock, partly compact. Slightly yellowish tinge.	Ditto.	. . . .	+	+
225	White.	Rather porous, partly oölitic.	Ditto.	. . . .	Very few.	+
250	White.	Soft, porous, granular, somewhat oölitic.	Relatively large amount.	. . . .	. . . .	. . .
275	White.	Rather solid sand-rock, with some amorphous limestone.	Ditto.	. . . .	Very few.	. . .
300	White.	Sand-rock, with some dense limestone and a little oölite.	Ditto.	. . . .	?	. . .
325	Yel. wh.	Sand-rock, containing a few ovules.	Ditto.	+	. . . .	*
350	Yel. wh.	Rather coarse sand-rock.	Small amount.	. . . .	+	+
375	Yel. wh.	Rather coarse sand-rock, containing a few ovules and some dense limestone.	Ditto.	. . . .	+	+
400	Gray.	Loosely compacted sand-rock, containing porous hard white portions. Partly oölitic.	Present in notable amount.	Very few.	+	. . .
425	Gray.	Sand-rock, like the last above.	Relatively large amount.	. . . .	Few.	Few.
450	Gray.	Ditto.	Very small amt.	. . . .	. . . .	. . .
475	Gray.	Ditto.	Small amount.	. . . .	. . . .	+
500	Gray.	Ditto, with the addition of gray dense limestone.	Ditto.	. . . .	+	*
525	Gray.	A friable sand-rock, with lumps of hard, white, porous limestone.	Ditto.	. . . .	?	+
550	Dk. gr.	Very friable sand-rock, with almost no bits of the white.	Ditto.	. . . .	. . . .	. . .
575	Dk. gr.	Ditto; with oölite present.	Ditto.	+	Rare.	. . .
600	Lt. gr.	Friable sand-rock, with many bits of white.	Sm. amt., very fine grained.	. . . .	. . . .	?
625	Gray.	Like the above, but w. fewer white bits. Some ovules.	Ditto.	+	. . . .	?
650	Gray.	Ditto; with pieces of oölite.	Very sm. amt., and very fine grained.	. . . .	. . . .	+
675	Gray.	Ditto; with pieces of oölite.	Ditto; but with more of the larger rounded grains.	+	. . . .	+

Record of the Artesian Well at Key West, Florida.

Bryozoa.	Lamel.	Gastr.	Remarks.
....	....	....	This is a somewhat friable oölite. The quartz sand is very fine, limpid, angular.
....	....	....	Very friable oölite.
....	*	Few.	Mainly a shell limestone with much foraminiferal rock and oölite.
....	+	....	Almost white in color.
....	*	...	Pectinoids were noted among the lamellibranchs.
....	*	....	Partly an oölite, some of which is firm and some friable. There are many isolated ovules. Mostly a very porous rock.
....	*	....	Many rounded grains in the rock, but very little true oölite. Many angular bits of dense crystalline limestone.
....	*	....	Like the preceding in the main.
+	+	+	Sample is a fine sand containing very few determinable organic remains.
+	*	Very few.	Relatively coarse *rounded* grains of quartz are present. Very few determinable organic remains.
....	Very few.	....	Some of the rounded grains of quartz are 1 mm. in diameter.
+	*	....	Determinable remains very scarce.
+	+	Very few.	Noted some nullipores? Structure in thin section resembling the Palæozoic *Stromatopora*. [Can this be a nullipore?]
+	+	Very few.	Noted some nullipores? and some annelid tubes singly (*Spirorbis?*) and in groups.
....	+	....	A few relatively large fragments of coral are in the sample, and some annelid tubes.
....	*	....	Remains of some annelid tubes are present. Very, very little of the sample is determinable.
+	*	Very few.	Nullipores? and annelid tubes are present.
Very few.	*	....	The quartz sand contains relatively large, rounded grains. A single minute brachiopod (*Cistella?*) was noted.
....	Scarce.	....	Fewer of angular fragments of solid limestone than in 425. Almost no determinable remains.
Very few.	+	....	Still less solid limestone. Next to nothing determinable.
+	*	Very rare.	Thin section shows an organism made up of branching, anchylosed tubes similar to that in 300.
....	*	....	A fragment shows the network of tubes like that at 500 and 300 feet. Some lumps of oölite.
....	....	....	The quartz sand is relatively coarse and rounded. Recognized no determinable fragments of organisms.
+	+	Rare.	Foraminifera are *Amphistegina?* and *Cristellaria?*
....	+	....	A few ovules. Almost nothing determinable. Considerable granular calcite.
....	+	....	Some ovules. Almost nothing determinable. Branch of a calcareous alga?
....	+	....	Piece of an alga? Almost nothing determinable.
....	+	....	Great dearth of referable organic remains.

Record of the Artesian Well at Key West, Florida.

Depth.	Color.	Texture.	Quartz Sand.	Foram.	Corals.	Echin.
700	Yel. wh.	Uncompacted? sand with ovules and sm. bits of oölite.	Very, very sm. amount.	. . . .	. . . .	+
725	Yel. wh.	Mostly a "shell rock," with some oölite.	Trace.	*	. . . .	+
750	Yel. wh.	Porous rock, with ovules.	Very sm. amt.	+	. . . .	+
775	Very light yel. brn.	A hard porous rock with a few ovules.	Trace.	?	. . . .	+
800	Ditto.	Ditto.	More than the last 4 above.	*	. . . .	+
825	Ditto.	Ditto? More oölitic.	Small amount.	+	. . . .	+
850	Ditto.	Fine, uncompacted? sand, with many ovules.	Trace.	*	. . . .	. . .
875	Ditto.	Ditto, with few ovules.	Trace.	. . . .	. . . .	+
900	Ditto.	Loosely compacted sand-rock, with few ovules.	Trace.	*	+	. . .
925	Ditto.	Looks like a rather coarse beach sand.	Trace.	*	+	+
950	Ditto.	Ditto, with many ovules. Color a shade darker.	Trace.	*	+	?
975	Ditto.	Ditto, but contains angular fragments of rock.	Scarcely perceptible.	*	+	+
1000	Ditto.	Rather coarse sand-rock with rounded grains. Color a shade darker.	Ditto.	*	*	+
1025	Ditto.	A fine sand-rock with rounded grains.	Trace.	*	+	. . .
1050	Ditto.	Ditto.	Trace.	*	+	. . .
1075	Ditto.	Very fine sand-rock, with few ovules.	Trace, slight.	+	+	Scarce.
1100	Lt. brn. gr.	Partly porous and partly dense limestone.	Trace, slight.	*	*	+
1125	Lt. brn. gr.	Ditto.	Trace, slight.	*	*	Scarce.
1150	Lt. brn. gr.	Ditto.	Trace, slight.	*	+	+
*1175	Lt. brn. gr.	Ditto, partly oölitic.	Trace, slight.	*	+	+
1200	Lt. brn. gr.	More of a sand-rock than the four above, but much of it dense.	Very sm. amt.	*	*	Scarce.
1225	Very light brn. gr.	Very fine sand-rock, with many grains rounded.	Trace.	+	*	. . .
1250	Ditto.	Fine sand-rock, with some dense portions.	More than for 350 ft. above.	*	*	. . .
1275	Lt. brn. gr.	Sand-rock, with partly porous and partly dense portions.	Small amount.	*	*	+
1300	Lt. brn. gr.	Ditto.	Trace.	*	+	Scarce.
1325	Lt. brn. gr.	Fine sand-rock with ovules.	Trace.	*	+	. . .
1350	Lt. brn. gr.	A porous sand-rock, w. some dense portions and ovules.	Very sm. amt.	+	?	+
1375	Lt. yel. brn.	A fine sand-rock, with porous and dense portions and some ovules.	Wanting?	*	+	+
1400	Very light brn. gr.	Ditto.	Trace.	*	*	+

Record of the Artesian Well at Key West, Florida.

Bryozoa.	Lamel.	Gastr.	Remarks.
....	+	....	Looks like a loose beach sand, with almost no referable organic remains. Quartz grains various in size.
+	*	+	A globular foraminifer is rather abundant. The lamellibranchs are larger than usual.
+	*	+	More gastropods than usual. Some corallines ?
....	*	+	Highly fossiliferous. Shells and casts of pectinoid and other lamellibranchs most abundant.
+	*	+	Some shell fragments show the effects of boring organisms.
+	*	+	Annelid ? tubes and spicules of *Gorgonia*. More secondary calcite than usual.
....	*	+	Spicules of *Gorgonia* rather numerous.
....	+	....	Spicules of *Gorgonia* present. Sample is meagre in determinable fragments.
....	*	....	Nullipores? and spicules of *Gorgonia* present. *Orbitoides* appear in numbers.
+	*	Rare.	*Orbitoides* abounds. Spicules of *Gorgonia* not rare. Many white particles are in the sample.
Rare.	+	Rare.	Spicules of *Gorgonia* noted. Small proportion of referable organic remains.
....	*	Rare.	Seems to have been a loosely compacted rather coarse sand-rock.
+	*	+	Annelid tubes and *Vermetus ? Cæcum* and *Dentalium*. Spicules of *Gorgonia*. Gastropods more numerous than usual.
+	*	+	Foraminifera very abundant. Gastropods comparatively so. *Cæcum* and *Dentalium* present.
+	+	Scarce.	Largely composed of tests of foraminifera.
+	+	....	Very little is determinable.
+	*	+	Much more coarse material than in last above.
+	*	+	Fewer foraminifers than in preceding. The remains indicate comparatively large lamellibranchs.
....	*	+	Gastropods relatively common.
+	*	+	Gastropods more common than usual. Bits of coral less abundant than in the last above. Nullipores present.
+	*	Very few.	Few determinable fragments.
....	+	Very few.	Very, very little is determinable. There are a few angular bits of limestone present.
?	Scarce.	Very few.	Somewhat oölitic.
+	+	Very few.	Ovules are present, but scarce.
Scarce.	+	Very few.	Somewhat oölitic. As usual, most of the material is undeterminable.
+	*	Very few.	Very, very little is determinable.
+	+	+	Sample contains many angular fragments, but they contain very few determinable organic remains. Many rounded grains.
Few.	Few.	Few.	Some *Orbitoides* are very large, one 3.5 mm. across. *Textularias* appear. Very little coarse material, however.
Very few.	Few.	Few.	Foraminifers numerous and large, 4 mm.; many *Textularias*. The proportion of determinable fragments is large.

Record of the Artesian Well at Key West, Florida.

Depth.	Color.	Texture.	Quartz Sand.	Foram.	Corals.	Echin.
1425	Lt. yel. brn.	Fine loose sand-rock, with a very little solid limestone.	Trace.	*	. . . .	+
1450	Lt. yel. brn.	A very fine loose sand-rock.	Trace.	+	Rare.	. . .
1475	Lt. gray.	Ditto.	Trace.	+	+	. . .
1500	Lt. brn. gr.	Ditto, with a very little solid limestone in it.	Trace.	*	+	Scarce.
1525	Lt. brn. gr.	A fine, loosely compacted sand-rock.	Trace.	*	+	. . .
1550	Lt. brn. gr.	A porous limestone and sand-rock.	Trace.	*	?	+
1575	Lt. brn. gr.	A moderately coarse sand-rock, with some ovules.	Trace.	*	. . . .	+
1600	Lt. brn. gr.	A sand-rock containing porous and dense limestone.	Trace.	*	+	+
1625	Lt. brn. gr.	Ditto.	Trace.	*	+	+
1650	Lt. brn. gr.	Ditto, with more dense limestone.	Trace.	*	. . . .	+
1675	Lt. brn. gr.	Ditto; with less dense and porous limestone.	Trace.	*	. . . .	+
1700	Lt. brn. gr.	A fine sand-rock.	Very sm. amt.	*	. . . .	+
1725	Lt. brn. gr.	A moderately coarse sand-rock; rounded grains.	Very sm. amt.	*	?	+
1750	Lt. brn. gr.	Ditto, with some solid and some porous limestone.	Trace.	*	?	+
1775	Lt. brn. gr.	Ditto, with very little limestone.	Very little.	*	. . . .	+
1800	Lt. brn.	A very fine sand-rock, with very little solid limestone.	Trace.	*	. . . .	+
1825	Lt. yel. brn.	Ditto.	Trace.	*	. . . .	+
1850	Lt. yel. brn.	Ditto; but more solid rock.	Trace.	*	. . . .	+
1875	Lt. yel. brn.	Ditto, with some dense and some porous rock and oölite.	Trace.	*	?	+
1900	Lt. yel. brn.	A very fine sand-rock, with a little limestone and some ovules.	Trace.	*	+	+
1925	Lt. yel. brn.	Ditto.	Very little.	*	?	+
1950	Lt. yel. brn.	A very, very fine sand-rock with some ovules and a very little limestone.	Trace.	+	. . . .	+
1975	Lt. yel. brn.	Ditto.	Trace.	+	. . . .	+
2000	Lt. brn. gr.	Seems to have been a rather solid, very fossiliferous limestone.	Trace.	*	+	+

N. B. — In the foregoing table the sign + is used to indicate the presence of the organism in question in fair numbers for the sample concerned; and the asterisk is used to indicate a still larger number, comparatively. Such comparison is intended to be made only along the horizontal lines.

Record of the Artesian Well at Key West, Florida.

Bryozoa.	Lamel.	Gastr.	Remarks.
. . . .	+	. . . .	Not much is determinable, but what there is is mostly foraminiferal.
. . . .	+	. . . .	Almost all the sample went through the sieve, and is not determinable.
+	+	. . . .	Scarcely one per cent failed to pass the sieve.
+	+	. . . .	Very little is determinable.
+	Few.	?	The *Textularias* are the most common fossil.
+	+	Very few.	*Textularias* predominate among the foraminifera.
+	+	+	Much very fine sand in the sample. *Textularias* predominate, as above.
+	*	+	One piece of *Dentalium* observed.
+	Scarce.	Very few.	Highly foraminiferal, especially with *Textularia*. A few pieces of *Dentalium* were noted.
+	Scarce.	Very few.	Highly foraminiferal.
Few.	Few.	Few.	Proportion of determinable fragments rather small.
+	Very few.	. . . .	Very little is determinable. Ovules present?
+	Very few.	. . . .	The quartz sand contains relatively large, rounded grains. Some granules are doubtfully referred to ovules.
+	Very few.	. . . .	The *Textularias* are abundant. Ovules?
. . . .	+	Very few.	Highly foraminiferal, with same genera. Ovules ?
+	+	. . . .	Foraminifera constitute the major part of what little is determinable. Ovules present ?
+	+	?	Small proportion determinable; mostly foraminifera; particularly *Textularias* and *Orbitoides*.
+	+	+	Ditto.
Scarce.	+	Very few.	Contains internal cast of a *Pseudoliva?* 3 mm. high.
+	Few.	Very few.	Some fragments resemble calcareous algæ, while others are portions of burrows and worm tubes.
+	Few.	. . . .	Some fragments doubtfully referred to nullipores.
+	Few.	. . . .	Almost nothing determinable.
+	Few.	. . . .	Almost nothing determinable.
+	+	Very few.	An occasional rounded particle is too large for the sieve No. 40. *Textularias* predominate among the abundant foraminifera.

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A VISIT TO THE GREAT BARRIER REEF OF AUSTRALIA IN THE STEAMER "CROYDON,"

DURING APRIL AND MAY, 1896.

By Alexander Agassiz.

With Forty-two Plates.

CAMBRIDGE, MASS., U. S. A.:

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No. 4. — *A Visit to the Great Barrier Reef of Australia in the Steamer "Croydon," during April and May,* 1896. By ALEXANDER AGASSIZ.

THE EASTERN COAST OF QUEENSLAND.

No better introduction can be given for the study of the problem of the evolution of the Great Barrier Reef of Australia than a general sketch of the Physical Geography of the Northeast Coast of Australia from Moreton Bay to Cape York. I shall illustrate my remarks by a series of charts and sketches of the most characteristic parts of the coast, selected with special reference to our subject. (Plates XXIII. to XXXVI.) These will show the gradual encroachment of the sea upon the northeastern edge of the continent of Australia. We shall then follow the submarine extension of the coast, and from the soundings given on the English Hydrographic Charts select a number of lines across the continental platform which will give us a fair idea of the sea-face slope upon which the outer edge of the Great Barrier Reef is situated. (Plates XXXVII. to XLI.) This will be followed by a few charts illustrating that part of the reef which we examined somewhat in detail, and from which I have ventured to build up an explanation of the causes which have been mainly efficient in the shaping of the Great Barrier Reef as it stands to-day.

Beginning at the latitude of Brisbane, the coast is flanked by the islands of Stradbroke and Moreton, both of which rise to over six hundred feet (Plate XXVI.). The former island is separated from the mainland at its southern extremity by a shallow and narrow passage, while towards the north the island is separated from the mainland by a number of low islands, one of which attains a height of 250 feet. Between the islands, flats and bars are left uncovered at low tide between the deeper parts of Moreton Bay. Similar banks and islands flank the right bank of Brisbane River near its mouth. Moreton Island is separated from the mainland by a series of bars and flats running in a northerly direction, between which run the two principal

channels leading into Moreton Bay from the north. The south channel leading into that bay runs between Stradbroke and Moreton Islands. About eighty miles north, we come upon a second and similar projection from the main coast line. Great Sandy or Frazer Island is a long spit rising to 800 feet at one point (Plate XXVII.), its northern extremity forming the eastern side of Hervey Bay, while its southern half is separated from the low coast of the mainland by a strait varying from one to six miles in width, into the northern end of which flows the Mary River. The Great Sandy Strait is filled with small low islands or with extensive flats, leaving only a narrow channel navigable for small vessels. A mere examination of the charts plainly shows that Great Sandy Island as well as the islands forming Moreton Bay once formed a part of the adjoining mainland; that they have been gradually separated from it by erosion and by the combined action of the scour of Brisbane and of Mary Rivers; while Breaksea Spit, with the adjoining shoals, covered with sand and dead coral, parts of which are awash, is the remnant of a former extension of Frazer Island, stretching about seventeen miles beyond Sandy Cape.

From Hervey Bay the coast takes a more westerly trend. Between Boyne and Fitzroy Rivers, lies Curtis Island (Plate XXVIII.), which at its highest points rises to more than 450 feet. The southern extension of Curtis Island is known as Facing Island; the latter is separated from Curtis Island by shallow flats, the Pelican Banks. The widest part of the channel between Facing Island and the mainland is not more than two and a half miles; at its southern extremity the channel gradually narrows, and at the "Narrows" Curtis Island may be said to be still united with the mainland; the channel to the north of the Narrows gradually widens until it unites with the Fitzroy River close to its mouth.

Parallel with the line of the mainland, at a distance of from thirty-five to forty miles, extends a line of low coral islands, forming the Bunker and the Capricorn groups (Plate XXVIII.). As an outlyer to the former group is Lady Elliot Islet, about half way between it and Breaksea Spit. From the Capricorn group a line of islands extends at right angles to the general trend of these groups, which is in continuation of Breaksea Spit to within twenty miles of the mainland.

The ten fathom line is close to the shore of the mainland; the slope of Curtis Channel is very gradual, falling somewhat irregularly to twenty-three to thirty fathoms as a general rule close to the line of the western edge of the southern island groups named above, and from twelve to eighteen fathoms off the northern Capricorn Islands. The channels

separating the islands vary from eighteen to thirty fathoms. Lady Elliot Islet rises from water a few fathoms deeper, while the islands of the Capricorn group which run in a southerly direction come up from a depth of ten to twenty fathoms. To the north of Keppel Bay, the Keppel Islands are less than seven miles from the coast, and are connected with it by extensive shoal patches.

Shoalwater Bay (Plate XXVI.) is flanked on the east by the Peninsula Range Point, the summits of which rise to over 1,700 feet, and by Townshend and Leicester Islands and the Cannibal group. The extension of the Normandy range (over 2,500 feet in height), separating Shoalwater Bay and Broad Sound, forms an extensive peninsula to the east of Broad Sound, the extremity of which is formed by numerous islands and flats, while on the west side of the main channel leading to Broad Sound the Flat Islands, with their shallows and flats, project from the mainland across a part of its northern opening.

North of Broad Sound Channel, over an area nearly sixty miles wide by a somewhat greater length in a northerly direction extend irregularly scattered islands, some of them of considerable size and height (Plate XXIX.), the Guard Fish cluster, the Northumberland Islands (over 700 feet), the Percy Islands (over 800 feet). The southern islands rise from an extreme depth of thirty fathoms, while the northern ones are within the ten fathom line; they are all rocky and of the same geological structure as the adjoining mainland.

Separated from the outermost of these islands by a wide channel, with a depth of from thirty to forty-five fathoms, we come, at a distance of about forty miles, upon the inner edge of the Great Barrier Reef, the northern extension of Swain Reefs, the southernmost outlines and the inner and outer edges of which alone have been sketched on the hydrographic charts. The depth off the eastern face varies from twenty fathoms close to the reef to thirty-five at a distance of from one and a half to two miles seaward.

The greatest width of the disconnected patches known as Swain Reefs is nearly seventy miles, and they extend in a northwesterly direction nearly unbroken for more than 150 miles. Swain Reefs are known from the description which Jukes gives of sailing through their labyrinth of broad and deep channels. Whitsunday Passage is a comparatively deep channel from fourteen to twenty-four fathoms, separating the mainland and the small islands close to it from the northern extremity of an extensive chain of islands, the Cumberland Islands (Plate XXX.), reaching from Hayman Island on the north to Penrith and the adjoin-

ing small islands on the south. The summits of many of the islands reach considerable heights. Hook and Whitsunday Islands are over 1,400 feet in height ; one of the smaller islands, St. Bees, is over 1,200 feet, Shaw Island is more than 1,300 feet, and many of the lesser islands rise to heights between 500 and 900 feet.

The islands to the east of Whitsunday Passage rise from the ridge within the twenty fathom line, as those of the Cumberland Islands on the same side of the Hillsborough Channel rise from the ridge within the ten and the twenty fathom lines (Plate XXX.). The inner edge of the Barrier Reef is about twenty miles from Penrith Island, and perhaps thirty from Whitsunday Island. Its depth is most irregular, — within the limits of the twenty fathom line on the west, and twenty-five to thirty fathoms close to the line of the reef patches on the inner edge of the Barrier Reef. The soundings in the channels within the reef patches gradually deepen towards the outer edge of the Barrier Reef from twenty to thirty-five or thirty-six fathoms. In this part of the inner Barrier Channel there are only a few small reef patches to the east of Penrith Island, which are the westward extension of the inner limits of the Barrier Reef. Penrith Island itself is flanked by a small coral reef flat. To the westward of Whitsunday Passage the coast shows but few traces of erosion, Gloucester Island and Magnetic Island being the only two islands of any size occurring in a stretch of about 120 miles, until we reach the Palm Islands (Plate XXX[a].). Edgecombe, Abbot, Upstart, Bowling Green, Cleveland, and Halifax Bays are deep indentations, the eastern promontories of which are still connected with the mainland, and have not as yet been separated from it, as have Gloucester and Magnetic Islands.

Off Hook Island, the inner edge of the Great Barrier Reef patches is less than twenty miles distant, and their width about thirty miles. On the inner edge off Hook Reef, the depth of the inner channel varies from twenty-four to thirty-four fathoms, and the sea-face slopes gradually from the outer line of patches from ten to forty-five fathoms towards the 100 fathom line, distant about ten miles. At the inner entrance to Flinders Passage the depth is about twenty-five fathoms, the distance from Cape Upstart being twenty-five miles, where we find ten fathoms close inland, and the fall gradual from there to the outer entrance of Flinders Passage, thirty-seven fathoms, at a distance of about sixty miles.

The reef is not more than twenty-five miles wide between the north side of Flinders Passage and the northern side of Palm Passage, the outer entrance of which is about fifty miles from the Palm Islands,

in a depth of ninety fathoms, sloping rapidly to thirty-five fathoms in a distance of about six miles, and very gradually to sixteen fathoms close off the Palm Islands. The slope of Magnetic Passage is similar to that of the Palm Passage. The triangular cluster of reef patches separating Magnetic and Palm Channels is about fifteen miles by ten (Plate XXX.[a]).

The reef gradually narrows north of Palm Passage, so that off the North Barnard Islands it is not more than from ten to twelve miles wide, the inner edge approaching at the same time the mainland. Off Double Point the inner edge of the reef is not more than twelve miles distant. From there to Cape Tribulation the inner edge of the reef is nowhere more than six to eight miles distant from the nearest headlands, and its width varies from six or eight miles to twelve or fifteen. Flora Pass, Grafton Passage, and Trinity Opening slope very gradually, the first from thirty-five fathoms to the three fathom line in a distance of thirty miles, the second from thirty-five fathoms to the ten fathom line in a distance of about twenty miles, while in the last the 100 fathom line is only about thirty-five miles from the mainland. The soundings in the opening are irregular, but from the inner edge of the reef for a distance of fifteen miles the slope is gradual from twenty-four fathoms to the three fathom line.

The northern extremity of Halifax Bay is flanked by the Palm Islands (Plate XXX[a].) for a distance of over fifteen miles. One of the summits of Great Palm Island is over 1,800 feet in height. The Palm Islands are outside the ten fathom line; the northernmost island is seven miles distant from the mainland, near the southern entrance of the narrow and deep Hinchinbrook Channel, which divides the mainland from the large island of the same name. Hinchinbrook Island (Plate XXXI.) is mountainous. More than twenty miles long, its greatest breadth is fully ten miles, and several of its peaks are more than 3,000 feet high. As seen from the sea, the island seems to consist of a short chain of mountains, in every way similar to those of the parallel range on the mainland, and to be separated from them by a deep valley. On the northern extension of the Hinchinbrook plateau inside the ten fathom line come Goold Island, the Brooke and Family Islands, Dunk Island, and the South and North Barnards (Plates XXX.[a], XXXI.). From there northward (Plates XXXII. to XXXIV.), with the exception of the Frankland Islands, of Fitzroy Islands, the Low Isles, and Snapper Island, there are no islands of importance on the long stretch of coast to Cape Tribulation. But we are now in the midst of a reef region in which the patches are more circumscribed, and not only better defined, but also better known.

The promontory of which Cape Grafton (Plate XXXI.) is the extremity is interesting as being a point which but slight additional erosion would soon separate from the mainland.

At the Hope Islands (Plate XXXII.) the reef may be said to have encroached to the fullest extent upon the flats which surround these islands; they rise inside of the ten fathom line, and are not more than two miles distant from the inner edge of one of the most interesting reef patches (Cairns Reef) of this part of the Great Barrier Reef.

Both the Cairns and Endeavor reef flats rise from about fourteen fathoms, and the distance from the inner edge of the reef patches to the outer edge of the reef patches is about fifteen miles. The deeper soundings close to the inside edge of the outer reef patches vary from ten to twenty fathoms; the 100 fathom line is from two to three miles from their outer edges.

At the Hope Islands and extending to a point west of Cape Flattery (Plate XXXIII.) begin a series of reef patches which have been more carefully surveyed than those more to the south, so that at certain stretches of this part of the coast our knowledge of the topography of the reef flats and patches, extending the whole width of the reef, is fairly complete.

The only rocky islands within the ten fathom line are the Low and Rocky Islets, and in addition we find within and outside the ten fathom line a series of reef patches and reef flats which from their position and condition we may fairly assume to be the remnants of former islands once a part of the mainland and now covered on their surface mainly with dead corals, while the slopes are covered with more or less flourishing belts of coral extending to between the seven to ten fathom belt. These reefs are, beginning at the Hope Islands (Plates XXXII. to XXXIV.), successively lettered from Eh (**a**) Reef to En (**n**) Reef, a reef patch lying to the north of the Turtle group. Some of the larger patches, such as **e** Reef, Turtle Reef, Aitch (**h**) Reef, El (**l**) and Em (**m**) Reefs, and Eagle Reef, all of which are well isolated reef patches rising from twelve to fourteen fathoms in the channel between the inner edge of the Great Barrier Reef and the mainland. These patches undoubtedly represent the eroded flats of former islands, some of them of considerable size, which occupied the main part of the coast channel, much as the group of the Lizard Islands, the Turtle group, and the Rocky and Direction Islands now do.

From the Hope Islands to off Cape Bedford (Plates XXXII., XXXIII.) the width of the Barrier Reef patches varies from twelve to fifteen miles.

The outer edge of this portion of the reef is formed by a series of linear or curved reefs of but little width, separated by deep and narrow channels, against which thunders the incessant Pacific swell. The inner edge of this line of reef patches is separated from the irregularly shaped reef patches which constitute the width of the reef by deep tongues of water, forming a more or less irregular deep continuous navigable channel of from ten to twenty fathoms, or even more, and of very variable width. Off Cape Bedford to the north of Lark Reef the reef patches become more distant and distinct, and as far north as Direction Island they are often widely separated. The reef flats of the inner part of the reef between Lark Reef and Aitch (**h**) Reef especially are widely separated, leaving an almost uninterrupted passage from Lark Reef to Lark Passage on the south, and similar passages to the north leading to the interior channel immediately to the eastward of the cluster of reef patches lying east of Aitch Reef and the Lizards and the narrow outer line of disconnected exterior reef patches extending from Lark Opening to One-and-Half-Mile Opening.

This outer interior channel north of Lark Opening varies in depth from ten to fifteen fathoms. East of North Direction Island it opens out into a broad bay from ten to twelve miles wide, reaching round the Lizards to north of the Turtle Islands, the narrow line of linear reefs forming its eastern boundary. North of One-and-Half-Mile Opening the reef patches within the outer line of reefs again constitute a belt varying from ten to twelve miles in width. We did not extend our examination beyond the line of the Lizard Islands and Eagle and Em (**m**) Reefs. Both these reefs are within the ten fathom line.

South of Cape Flattery (Plates XXXIII., XXXIV.) the Low-wooded Isle, Three Isles, and Two Isles are the only remnants of the numerous but somewhat widely separated islands which once existed between that cape and the outer edge of the Barrier Reef, the others having been eroded and changed to the reef flats and patches now existing to the eastward of these islands. Going north we come upon the Rocky Islets, South and North Direction Islands, and the Lizard group, the last of which occupies a considerable area and rises to a height of nearly 1,200 feet. The windward faces of all these islands and the flats surrounding them are flanked by coral, growing on their slopes and rising from a depth of from seven to ten fathoms.

To the north of the Lizards the outer edge of the Barrier Reef trends more to the westward, running parallel to the coast of the mainland to off Cape Melville, where it is not more than twelve miles from the coast,

the inner reef patches leaving only a narrow channel close to the mainland. The reef then turns north again, extending parallel to the coast line as far as Cape Grenville, at a distance varying between fifteen and thirty miles, but as the coast approaches that cape it trends somewhat more easterly, the outer edge of the reef gradually becoming more distant from the coast, until at the latitude of Cape York it has attained a width of over eighty miles, and forms a huge plateau within the twenty fathom line, irregularly studded with reef patches which connect New Guinea with the Australian continent. To the westward of Eagle Reef, En Island and the Turtle group are the only islands between the inner reef patches and the mainland.

An examination of the charts (Plates XXIV., XXXV., XXXVI.) shows that the northern part of the Great Barrier Reef presents as far as it has been surveyed no features differing from those of the southern district which it has been our fortune to examine. Everywhere a series of islands rising upon the continental plateau scattered between the mainland and its outer edge, with irregular patches of reef flats and reefs, growing upon the remnants of former islands which have been reduced to their present level by erosion and denudation, all apparently having formerly formed a part of the eastern extension of the Australian continent.

The Great Detached Reef and Yule Reef alone are exceptions to this. When we come to the region about Cape York we have exemplified in the stretch extending between Australia and New Guinea the conditions which once existed between the east coast of Queensland and the outer edge of the Great Barrier Reef. The group of islands to the west of Cape York, extending nearly across to New Guinea from Prince of Wales to Jervis Island, the northern group of which is separated from the southern cluster by extensive reefs and reef patches, give us an admirable idea of the manner in which the islands have little by little been first separated by erosion from the mainland, denuded, and cut down many of them to the water's edge, then pounded into flats, and finally their slopes covered with corals. While the line of islands and reefs extending in a northeasterly direction from Cape York, the group of the Adolphus Islands, and the series of reef patches extending almost continuously as far as the Warrior Reefs, are the remnant of a series of outer islands which have all, except those nearest Cape York, (the Adolphus and Albany Islands, and the Darnley and Murray Islands to the east,) been subject for a longer time to the same processes which have gradually cut away the land connection between Australia and New

Guinea,[1] or eroded the archipelago lying between them and the channels of moderate depth separating the islands and flats which have been cut by the tides, currents, and action of the sea.

Beyond the 100 fathom line there are a number of detached reefs, which seem to indicate the existence of very extensive plateaus of moderate depths extending off the continental plateau of the Great Barrier Reef, as, for instance, off Swain Reefs: the Saumarez Reefs; in the channel separating them from the continental plateau, 199 fathoms is indicated; in the latitude of Port Denison, 230 fathoms is the greatest depth found in the channel 120 miles wide separating Marion Reef from the continental slope.

In the latitude of Flinders Pass to Cook's Passage there is a channel of about sixty miles in width, varying from about 600 fathoms to 1,300 fathoms, which separates an immense triangular plateau, bounded to the eastward by the 1,000 fathom line, 250 miles by about the same base with a depth varying from 800 to 300 fathoms, upon which crop out a number of reefs: the Flinders Reef, Flora Reef, Herald Cays, Holmes Reef, Osprey Reef, Diana Bank, Willis Group, Magdelaine Cays, Tregosse, and Lilian islands and reefs. Unfortunately no soundings exist to show whether these banks are connected, and are parts of a single plateau, or are separated by deep channels.

THE GREAT BARRIER REEF.

We may now proceed with the description of the coral reef flats and patches, which we examined on our way from from Breaksea Spit to the Lizard Islands[2] (Plates XXIV., XXV., XXVII. to XXXIV.).

[1] See the conclusions of an interesting paper by Professor Haddon on the geological relationship of Queensland and New Guinea, (Transactions of the Royal Irish Academy, 1894, Vol. XXX. p. 467,) and descriptions and sketches of some of the reefs in the Torres Strait scattered through his account of the geology of the Strait, *loc. cit.*, page 420 and following.

[2] Professor E. S. Dana published an extract from a letter to him dated Cooktown, Queensland, May 16, in the September number of "The American Journal of Science," 1896, p. 340, giving a summary of the results obtained during my visit to the Great Barrier Reef.

The steamer "Croydon" of the A. U. S. N. Co. was chartered for my exploration of the Great Barrier Reef. Dr. W. McM. Woodworth and Mr. A. G. Mayer accompanied me as assistants. We carried a complete photographic apparatus and an extensive outfit for pelagic fishing in the way of surface as well as of deep-sea Tanner nets, with the usual apparatus for sounding in moderate depths. All this,

Breaksea Spit (Plate XXIII.) may be said to be the dividing line between the Barrier Reef coral district and the southern extension of corals, which, though belonging to reef building species, yet have nowhere flourished luxuriantly enough to build more than thin stretches of coral patches, the southernmost limit of the coral fauna being Moreton Bay, at the mouth of the Brisbane River. As has already been observed by Kent, the corals of that part of the Queensland coast are limited in their development by local causes, and in the southern extension of the reef building corals of the Barrier Reef we find the same phenomena characterizing their diminished growth which mark their northern extension on the east coast of the United States north of the Florida Reef. Their disappearance in the Atlantic is, however, mainly due to the temperature of the water, while on the Queensland coast their disappearance was also affected by the great amount of sediment brought down the Brisbane River, and which is gradually silting up Moreton Bay.

It is a curious coincidence, however, that at Breaksea Spit, as well as at Cape Florida, we should find the encroachment of the silicious sands, in one case coming from the north along the coast of Florida, and in the other coming from the south along the shores of Frazer Island, gradually prevent the farther northern and southern extension of coral reefs in the two regions.

Dead corals are constantly thrown up upon the beach to the north of

beside the necessary appliances for preserving the collections, was forwarded to Sydney early in the winter.

Commander Z. L. Tanner, U. S. N., was kind enough to superintend for me the building of the sounding machines and of the deep-sea nets. We hoped to make large collections of pelagic animals, both inside the Barrier Reef as well as at sea off the passages leading through the reef. Unfortunately, during our whole stay in the district of the reef, boisterous weather prevented us from carrying out our plans for making pelagic collections, and we were compelled to limit our work mainly to the examination of the inner portions of the Great Barrier Reef district.

I have to thank the State Department at Washington, the Foreign Office in London, and the government of Queensland, for the interest they took in the expedition, and for the facilities for work offered me in consequence from every direction.

I am specially indebted for valuable information and advice to Admiral Wharton, R. N., and to Commander C. D. Sigsbee, U. S. N. I owe my thanks to Mr. W. Saville Kent, Dr. R. L. Jack, Captain Thomson, and the officers of the "Croydon," for their interest in the expedition. The managers of the Australasian United Steam Navigation Company and their agents from Sydney to Cooktown were indefatigable in attending to the wants of our party.

the lighthouse on Breaksea Spit, and from the information gathered by the keeper, as well as from the character of the soundings upon the bank, indicating the former extension of Breaksea Spit, it is evident that the corals upon the spit are dead, and that they probably have been killed by the encroachment of the silicious sands creeping northward on the surface of the spit, and from which have been thrown up the fine sand dunes over 300 feet in height which exist on the northern part of the spit.

This silicious sand is constantly overwhelming the few corals which manage to get established on the spit, and prevent their further growth, much as the silicious sands of Cape Florida are constantly mixing with the calcareous sand derived from the coral reefs immediately to the south of it.

Owing to the heavy sea running, we were unable to land at Lady Elliot Islet or to examine the pseudo atolls of the Bunker and Capricorn Island groups. Judging however of their structure from the charts and from the excellent description of some of them given by Jukes and the illustrations of Lady Elliot Islet by Kent, and from what I saw subsequently of reef flats which must have been very similar to those of Elliot Islet and of similar islands of the adjacent groups,[1] I imagine that causes very similar to those which have dug out miniature atolls at the Bermudas have acted on a larger scale at these islands. First, the sea wearing away the islets, which may have risen to a considerable height, to the level of the sea, forming a flat on the weather side upon which the swell gradually digs out a shallow lagoon, and on the outer edge of which corals thrive, growing more luxuriantly on the outer and windward edges. The many shaped coral islets, either with[2] or without[3] remaining pinnacles, attest to their former and greater extent. In some cases all trace of the underlying rocky platform has disappeared, and it has become coated with corals.

North of Swain Reefs and south of Flinders Passage, the Barrier Reef has been reconnoitred by Captain Flinders, who sketched in a general way the inner limit of the reef patches, and something of the condition of that part of the Great Barrier Reef is known from the track of

[1] Lady Elliot Islet is the most southern of the coral reefs of the Great Barrier Reef. It rises some eight or ten feet above high-water mark. Jukes has figured the general aspect of the island (Voyage of the "Fly," Vol. I.), and Kent has given a fine view of the coral reef flat (Great Barrier Reef, Plate XXXIII. B).

[2] Lady Musgrave, One Tree, Heron, Masthead, Wreck, and N. W. Islands.

[3] Boult, Llewellyn, Fitzroy, Wistari, and Polmaise Reefs.

the ship "Wansfell." In 1864 she passed into the reef through an unknown opening about latitude 20° 30′ S., and came out opposite Port Denison.

As we proceed northward, corals become more and more abundant, skirting parts of the islands from which too great quantities of detritus are not washed down in the rainy season, or wherever a locality presents itself, favorably placed as regards the food supply or the purity and depth of the water.

On our way north from Keppel Bay we could only examine the numerous islands we passed in the most superficial manner. The state of the sea prevented us from landing either at any of the Northumberland Islands, or the Percy Islands, or the southern group of the Cumberland Islands. It was only when we reached the southern extremity of Whitsunday Passage (Plate XXX.) that we were able to examine the small reefs which skirt part of the shores of the greater number of the larger islands forming the eastern belt of the passage.

The bank in Cid Harbor (Whitsunday Island) to the north of our anchorage, which slopes gradually from the shore to two or three fathoms, was covered by fine masses of coral. They apparently did not stretch into deep water, for near our anchorage, which was in only six fathoms, there were no corals, the bottom being mud and broken shells. The corals formed a belt (a kind of plateau) of a certain width on the slope. The Astræans were marked for their size. Huge masses of whitish Alcyonaria were very active, the long-stemmed individuals of the colony twisting and bending in all directions. The abundance of soft masses of Alcyonaria seems to be a characteristic of the coral reefs of Australia, where they replace the Gorgonians of the West Indian reefs. The masses of Astræans, of Mæandrinas, and of Porites were also uniformly larger than we find them on the West Indian coral reefs. Between the heads were buried Tridacnas of varying sizes, and sponges were also far more common than is the case in the West Indian reefs.

At Langford Island (Plate XVIII.), a small island at the northern extremity of Whitsunday Passage, we examined the coral reef which extends for about a mile to the south and east of the island. The two extremities of Langford Island are connected by a sandbar, and on the slopes of the reef flat, which is bare at low water, corals flourish in from two to three fathoms. At the southern extremity of the reef flat are two low islands, the remnants of the spit which once connected them with the higher island at the other end of the reef flat. The

reef flat is partly covered with fragments of dead corals, and is undoubtedly underlain by the extension of the rocky platform of Langford Island, part of which crops out as the rocky islets mentioned above, the rest of the foundations having been worn away by atmospheric agencies above the water line, and by the action of the sea below that line.

On Woody Island, a small island to the east of Langford Island, the corals have similarly grown upon the slopes of the flat which surrounds the island, but the greater part of the island has been washed away, as has been Langford Island. The coral flat is somewhat lower in the middle than the outer edges.

Thus far, we found the water of the inner channel of the Barrier Reef comparatively muddy, considerable silt being held in suspension, and this greatly interfered with the use of the water glass, as often we could not clearly distinguish objects on the bottom beyond three or three and a half fathoms. This may be due to the constant prevalence of the trades, accompanied with rain, which scours the slopes of the coast lands and of the adjoining islands, sweeping into the inner channel a large quantity of silt.

At Port Denison we examined the reef off Adelaide Point mentioned by Kent. It is comparatively poor; a great part of it is dead, silted over by the material brought down by the river. There are a few fine heads in good condition, in about four fathoms, on the outer edge of this shore reef. But the greater part of the reef is covered with seaweed. Off Stone Island Reef (at the mouth of Port Denison), there are many insolated heads, a number of which are dead. The bottom of the bay is covered with fine mud and broken shells.

We reached Middle Island, about half way between Gloucester Head and Port Denison, at low water, a long flat shoal extending from the south face of the island. The outer face of this flat is coated with fine heads of corals rising from six to four fathoms, and becoming less prominent as they tend towards the shallower edge of the flat extending from a steep coral sand beach to low-water mark.

At the western extremity of this sand beach we come upon a fine exposure of a coarse conglomerate (Plate IV.) similar to that off Cape Upstart observed and described by Jukes.[1] This conglomerate beach rock is elevated fully eight feet above the highest high-water mark. It slopes towards the sea at an angle of from 8° to 10°. The Middle Island conglomerate is made up of fragments and rounded pebbles of

[1] Captain Stokes (Discoveries in Australia, Vol. I. p. 332, 1846) gives an account of a raised beach near Cape Upstart, twelve feet above high-water mark.

all sizes of the metamorphic rock forming the island. These pebbles are cemented with fragments of the rock oysters[1] which must once have grown upon the disintegrated faces, as they do now upon the faces of the rocks near low-water mark. The flat (Plate II.) exposed by the tide is slightly raised along the northern and southern edges, and partly surrounds a shallow pool which is covered with dead corals and masses of the conglomerate from the elevated reef rock, which must have extended fully three hundred yards from the shore, and been eroded to form the face of the slope of the existing reef. The dead coral which covers the reef flat is undoubtedly derived from the breaking up of the coarse elevated coral conglomerate, of which only here and there very large fragments are met with on the flat exposed at low water.

Associated with the granitic pebbles, and cemented with them in one solid mass, are found numerous fragments of many species of corals, mainly Madrepores however, which must have been thrown up when the elevated reef was flourishing, much as to-day we find the fragments of corals thrown up on high banks beyond high-water mark.

Such a pile of fragments of corals from the southeast end of Middle Island flats (Plate III.) has been photographed by Mr. Woodworth. This peculiar conglomerate reminds me very much of a similar conglomerate found in small patches at the base of Diamond Head (Oahu Island), a few miles from Honolulu. It is the same kind of conglomerate as that seen by Jukes at Cape Upstart and elsewhere on the east coast of Queensland, and which he mentions as evidence of a very moderate elevation of this part of Australia.[2] The old coral sand beach

[1] Kent has figured the Mangrove oysters from the estuary of the Endeavour River, near Cooktown, on Plate XXXIX., and on the same Plate also he has represented the solid reef-like masses of *Ostrea conglomerata*, which occur in Keppel Bay and in Moreton Bay. While at Middle Island, and many other places on the islands near the mainland, we came upon the incrusting and most characteristic coral rock oyster, *Ostrea mordax*, which flourishes in pure sea water, and has been so well figured by Kent on Plate XL.

[2] Jukes (Voyage of the "Fly," p. 335) writes as follows regarding the evidence of a moderate elevation of the northeastern part of Australia: —

"I wish to refer to the masses of coral conglomerate forming strips of flat land along shore behind the present beaches, and to the presence of pumice pebbles sometimes in that conglomerate, but more usually scattered over its surface loose upon the ground. . . . The coral conglomerate has been already described, especially that at Cape Upstart, and in the Capricorn group of islands. Flats composed of it, half a mile in width, are frequent along the shore of the northeast coast of Australia. It must either have been formed under water, in which case its existence as dry land proves elevation of the whole coast, or it must have been produced

behind the conglomerate beds is fully six feet higher than the conglomerate. The bottom at our anchorage, only a short distance from the face of the exposed flat, in ten fathoms of water, consisted of blue mud and of broken shells. The faces of the elevated conglomerate exposed to the action of the sea were pitted and honeycombed much as the æolian rocks of the Bahamas where exposed to the force of the sea.

The next coral reefs we examined were those of the Palm Islands. The corals off Great Palm Island rise from between four and six fathoms. They consist of masses of huge heads separated by coral sand lanes, and extend to water of one and a half to two fathoms in depth towards the shore. The amount of silt held in suspension in the water was as great here as farther south along the inner Barrier Reef channel.

Passing north from the Palm Islands (Plate XIX.), one cannot fail to be struck at the marks of the extensive denudation and erosion apparent on all sides. The domelike cliffs back of Townsville, the cliffs along the railroad of the Ross River valley, the angular peaks, the sharp ridges, the deeply cut valleys, the islands, islets, and rocks on the two sides of Hinchinbrook Island passage, all indicate the effective work of atmospheric agency (Plate XXX[a].).

The fine mud and silt which everywhere cover the bottom of the inner channels of the Barrier Reef indicates only too clearly where the telluric material has been swept to. In fact, this extends so generally over the bottom, not only near the main land in close proximity to the lower

by the piling action of the surf heaping up successive accumulations of calcareous sand, which has been subsequently compacted into rock. In the latter case, it never could have reached *a higher level* than it now has (a few feet above high-water mark), and its formation by this action must have required an immense period of time, during the whole of which *no depression can have taken place.* Upon all these flat spaces formed of this conglomerate, as well as upon all other flat land along the eastern and northeastern coast of Australia, which is not more than ten feet above high-water mark, there is found an abundance of pumice pebbles. . . . By whatever cause they were cast upon the land, their present position proves that the whole coast where they are found has been equally stationary, or equally affected by movements of elevation or depression since they were so cast. . . . That the advent of these pebbles is not a very recent event is proved by facts I observed on the northeast coast. I have picked up pumice pebbles, for instance, on sand and mud flats more than a mile from the sea. . . . Altogether, the evidence derived from the existence of the coral conglomerates, and the presence of pumice pebbles, to a height of eight or ten feet above the highest possible tides, proves to my mind that for a very long period the whole eastern coast of Australia has either been quite stationary, or has been affected by slight movements of elevation. It is clear, I think, at all events, that *no recent depression* has taken place throughout the district where either or both of these phenomena occur."

bathymetrical range of the corals of the inner reef banks, but also close to the limit where corals grow on the very inner edge of the outer line of the Barrier Reef. The existence of this telluric mud so close to the outer edge of the reef can only be due to the disintegrated land, islands, islets, and rocks which once existed close to the present outer line of the Great Barrier Reef, — land of which the only indication is the presence of innumerable coral banks which have grown upon its former sites, of islands which have either completely disappeared, or of which only an occasional trace is remaining in an isolated peak, or rocky bank, or a single rock.

We examined the western edge of Bramble Reef, lying to the northeast of the Palm Islands. The edge of that reef flat is lined with many clusters of negro heads.[1] Unfortunately the surf was too heavy for us to land and examine this most characteristic inner reef patch. The Family Islands (all within the ten fathom line) are of all shapes, and their aspect, as well as their vegetation of pine and gum scrub, and their geological features, clearly indicate their former connection with the adjoining part of the mainland. The Frankland Islands consist of metamorphic rocks. The depressions near the shore are filled, according to Captain Thomson, with coral conglomerate, and this is overlaid with broken coral and other marine débris.[2]

The slopes of Fitzroy Island (Plate XX.), like those of Cape Grafton opposite, show the usual marks of great denudation and erosion, the ledges of granitic rocks when exposed being rounded and worn, and broken up into huge boulder-like forms. I could not find on Fitzroy Island any trace of the elevated beaches mentioned by King. What he describes as such appear to me to be merely accumulations of fragments of dead corals thrown up by the sea well above high-water mark. This is specially well seen at the watering place in the middle of the coral sand beach on the northwest side of the island.

[1] The term "negro head" was first applied by Flinders to the large masses of coral flanking the edges of the reef flats. (Terra Australis, Vol. II. p. 83.)

[2] In order to ascertain the rapidity with which corals may grow and become attached to fresh surfaces, I asked Captain Thomson on his way south from Cooktown in the "Croydon" to place large blocks of stone under the Low Isles. He also laid a mark down at the Frankland Islands in a position where it would have the benefit of all the clean water and be free from the influence of the material brought down from the slopes of the islands. Captain Thomson reports walking over the reefs of the Low Isles, which we did not examine on our way north, and finding their surface covered with dead corals and negro heads along the outer edges.

On our way in and out of Cairns we passed Green Island, and the fine reef off that island, and examined also the weather reef of Trinity Opening. There is no passage between Green Island Reef and Arlington Reef to the eastward, which forms the northern edge of Grafton Passage. On the west side of Green Island there were patches of beach rock on the coral beach, and all along the west side of the extension of the reef negro heads could be seen well to the south, fringing the whole edge of the reef; a few were seen towards the southern end of the island. We skirted along the western edge of the Green Island and Oyster Reef banks. On the summit of the Southern Cay a few bushes grow a few feet above high-water mark (Plate XXXI.).

Eastern Oyster Cay is composed of coral sand, and is somewhat higher than the Western Cay. Its summit is covered with low scrub. A new sand cay not indicated on the charts, thrown up very probably since the last surveys were made, rises a few feet above high-water mark, and is destitute of vegetation.

Bramble, Green Island, Arlington, and Oyster Reefs are characteristic reef flats, such as exist on the eastern edge of the inner Barrier Reef channel. At low water many parts of them are bare, and at high water their presence is clearly indicated by the discoloration of the water over the extensive areas they occupy (Plate XII.). The deeper water of the channels separating them, from eight to twenty fathoms, stands out in marked contrast by its dark blue color, and renders exploration a comparatively easy task. The flanks of these reef flats are covered by extensive patches of reef corals, growing from depths of from seven fathoms either close to low-water mark in favorable localities, or to the edge of the great flats where the belt of negro heads begins, or where the remnants of the disintegrated elevated reef have covered the surface of the flat with masses of broken corals and coral heads, rendering the surface usually unfit for any extended growth of reef corals.

Trinity Opening, Grafton Passage, and Flora Pass are wide water ways,[1] flanked on each side by inner reef flats, more or less widely sepa-

[1] It has been suggested (Kent, Great Barrier Reef, pp. 111, 112, 132) that the great openings through the Barrier Reef were opposite the mouths of the principal rivers of Queensland (Trinity Opening, Flinders, Palm, Magnetic, Flora, Grafton Passages, Capricorn and Curtis Channels), and that though now from thirty to eighty miles distant, yet at one time these breaks were close to the mouths of the rivers, and owe their origin to the fresh water and silt brought down by them. The amount of silt brought down by the Barron River is such as to form an extensive flat off Cairns, extending well out toward Cape Grafton, and naturally interfering with the easy access to that harbor, and the same is the case with the other Queens-

rated, which lead towards the 100 fathom line, and form a uniformly sloping channel from the inner reef channel to the sea. There being no outer Barrier Reef patches, or outer reef channel, as along other parts of the reef (as south of Lark Pass, for instance, and elsewhere), where the outer Barrier Reef forms a series of linear or curved reefs, separated from the inner reef patches by a channel of from twelve to twenty fathoms in depth. With the exception of the few insignificant reef patches scattered across the middle of Trinity Opening, that channel is flanked on the north by Butt Reef and on the south by Oyster Reef, both of which are reef patches forming the eastern flank of the inner Barrier Reef channel (Plate XXXI.).

Before going on with the description of the inner and outer reef patches, it may be well to give that of the smaller island groups north of Trinity Opening as far as the Lizards, many of which are gradually changing into reef flats.

Continuing our examination of the islands situated between the inner western edge of the Barrier Reef and the mainland, we come north of Trinity Opening, first upon the Low Isles situated in midchannel. Close to the mainland is Snapper Island. About thirty-five miles north of the Low Isles we come upon the Hope Islands (Plate XXXII.).

The smaller of the Hope Islands to the east is a sandy island flanked on the southeast by an immense flat covered by dead coral (Plate VI.), and numerous fragments of beach rock, forming an irregular pavement. The fauna living under these stones is quite rich, and between them were found numerous huge Actiniæ, Alcyonarians, Zoanthus, and Annelids, as well as an occasional living coral. On the coral reef flat there were found many Tridacnas, Holothurians, long-armed Ophiurans, huge Synaptas, and splendidly colored Macrurans and Brachiurans.

On the slope to the leeward of the flat were growing fine patches of corals, with sponges, Actinians, Alcyonarians, Fungidæ, Millepores, huge masses of Pocillopora, Madrepores, heads of Astræans, of Gymnastræans, and of Mæandrinas. These heads and patches begin to make their appearance in from six to seven fathoms, increasing gradually in number and species to between five and three fathoms of water, where they

land rivers, like the Burnett, Fitzroy, and others. If there has been a subsidence of about 100 feet, as indicated by the river beds near Townsville, it is very probable that the course of the Queensland rivers extended farther out to the edge of the Great Barrier Reef, and that some of the breaks and passages extending westward may have been originally due to the action of the rivers, an influence at this day reaching only a comparatively short distance from the shores of the mainland.

form a nearly continuous belt coating the slope of the reef flat; the patches and heads diminishing again very rapidly in shallower water towards the inner edge of the reef flat where at low tide there is from two to three feet of water. The eastern Hope islet is low and woody with a steep coral sand beach, on which exists a small strip of beach rock. Negro heads of beach rock occur on the flat to the northwest of the western Hope Island. West Hope Island is like the eastern island, only somewhat longer[1] (Plate XXXII.).

We skirted along the eastern face of Turtle Reef to see the fine, somewhat scattering belt of negro heads which we had partially examined before. The reef to the east of Turtle Reef is on the north face flanked by numerous coral patches with lanes of deep water crossing the reef flat. On the east face there is a belt of huge negro heads.

About ten miles to the northeast of Cape Bedford we come upon the Three Isles (Plates VII. to XI.), which form a shallow lagoon (Plate XI.), bare at low tide. It is an interesting group, showing how an irregularly shaped atoll can be generated merely by the same action of the sea, which under certain circumstances forms an open arc, under others a bank just awash, or islands or islets with banks to indicate their former greater extension. These islands were included in the general elevation which raised the Great Barrier Reef a few feet above high-water mark. At several points on the outer shores of the islands there are long stretches of coarse beach rock elevated about eight feet above high-water mark (Plate X.).[2] Their former extent was of course much greater, and little by little the beach rock has been disintegrated and reduced to

[1] In the Hope Islands and other places ballast is often thrown overboard by the *bêche de mer* fishermen, and care should be taken not to mistake this ballast for remains of outcrops of rocks on the reef flats.

[2] Kent has given excellent figures on Plate XXXII. of coral breccia, of shell and rocky conglomerates and breccia, and has called attention to the rapidity with which their cementation takes place, a subject which has been frequently described by Dana, Darwin, Agassiz, and the many writers who have paid attention to the structure of coral rocks and the phenomena accompanying the formation of coral reefs.

Kent has very justly called attention again to the great development of some of the deep-sea corals, such as Lophohelia, Amphihelia, Dendrophyllia (in from 100 to 500 fathoms or more), and to the possibility of their forming coral rock quite as rapidly as some of the Madrepores if brought within the action of the surf. We might add to this list Oculina, which occurs so plentifully in the deeper protected sinks of the Bermudas, and which off certain parts of the southern coast of the United States forms quite extensive banks in waters of moderate depths (to 50 fathoms). Oculina is also found at the Galapagos under similar conditions.

form the coral sand beaches, or the greater or less fragments which cover the reef flats. The negro heads occurring on the edge of some of the flats (Plate VIII.) are all composed of beach rock, and remain as monuments of the former extension of the beach rock. The reef flats are strewn with the dead corals and shells which once constituted this coarse beach rock. The beach rock where it still stands is eroded, deeply pitted, and honeycombed by the action of the sea, and it resembles limestones similarly acted upon in other coral reef localities. The beach rock conglomerate of the Three Isles is however extremely coarse, made up of fragments of oyster shells and of all kinds of corals, once cemented together, but disintegrated by the work of the sea. Here and there a small vertical bluff of this conglomerate is left standing, showing its thickness and the height to which it was elevated above high-water mark (Plate XXXIII.).

I was at first puzzled with the mass of dead corals and of fragments of larger blocks left strewn over the reef flats (both on the inner and outer reefs), in from two to three feet of water at average low tide. The presence of negro heads, remnants of the former elevated coral reef, and of negro heads the remnants of former long stretches of elevated coral beach rock conglomerate, give us a ready explanation that their presence on flats where the sea could not have transported them is due to the disintegration and erosion of the coral reef and of the conglomerate when they extended over the surface of the reef flats.

On Plate XXX. of the Great Barrier Reef (see p. 49), Mr. Kent has given a view of huge masses of consolidated coral rock torn off, as he says, from the outer edge of one of the Capricorn Island group, and hurled far up on the face of the level platform reef. He called these huge masses "Nigger heads." Jukes rightly considers them as indicating a former elevation, and I fail to see that they show "direct evidence of subsidence rather than of elevation," as is stated by Kent, page 50.

The throwing up of such huge masses of coral rock is well known to occur in all coral reef regions. I have given figures of similar huge masses of rock washed up by hurricanes in the Bahamas.[1] But, as Kent well says, these phenomena "are mostly associated with the cyclonic storms that, during the prevalence of the northwest monsoon, occasionally sweep the reefs with irresistible force, though fortunately *over limited areas.*" The Italics are mine, and attention is called to the "limited areas" as the explanations given by Kent will not explain the occurrence on these grounds of "nigger heads" on the edge of so many

[1] Agassiz, Bahamas, Bull. Mus. Comp. Zoöl., XXVI. No. 1, Plate XXIV.

reefs, the weather, or the leeward edges, on the inner lines of reef patches.

The scene he figures as resulting in the wreckage of the fringing reef by a hurricane on Saddleback Island (Plate XXXI.) has nothing in common with the existence of "nigger heads" occurring on the edges of the reef flats, which are, as I think can be conclusively shown, the remnants left from the erosion of a much larger mass, as suggested by Jukes.

A little farther north, the condition of things existing at Two Isles is similar to that described at Three Isles. We find the same coarse beach rock and the negro heads remaining from the eroded elevated conglomerate; the coral reef flat connecting the islands forms an irregular lagoon, enclosed on the northwest side by the islands and the reef flat, and on the southern side by a somewhat deeper reef flat, from which rise a few negro heads. We were struck with the great number of dead Nautilus and Spirula shells thrown up on the sand beaches of the Three and Two Isles groups. Also by the masses of cuttlefish bones of all sizes which were found with them. These cuttlefish bones could often be seen floating by us in great numbers. The accumulation of such quantities of dead shells of Spirula, of Nautilus, and of Cuttlefish bones may give us a hint as to the mode of their accumulation in former geological periods, and certainly show how poor a guide they are of the character of the fauna of the district immediately adjoining the place of deposit.

The larger one of the Two Isles is a bank a few feet in height thrown up from the sand derived from the disintegration of the elevated beach rock flanking its side (Plate XXXIII.).

The Rocky Islets, South and North Direction Islands, and the Lizard Islands are among the best examples of rocky islets left as remnants of the former eastern extension of the Australian mainland. The southern of the Rocky Islets, with its bare rounded summit, shows admirably the extent of the denudation and erosion to which the islands of this part of the Australian continent have been subjected. Extending towards the southern islet a small reef flat has been formed from the extremity of the larger central island; a still smaller flat extends from the opposite extremity (Plate XXXIV.).

Lizard Island (Plates XXI., XXII.), as also the Direction and Rocky Islets, show wonderfully well, not only the great denudation and erosion that has taken place, but also that which is now going on. Huge masses of rock are pealing off in conchoidal fractures, and splitting up

into more or less rectangular blocks with rounded corners, often left stranded almost like boulders on the summit of the ledge from which they have originated.

Retracing our steps, we may now take up the description of the great coral reef flats which we examined between the Hope Islands and Lizard Island.[1] About five miles north of the Hope Islands we come upon b Reef, situated off the northwest extremity of Endeavour Reef (Plate V.). It is a long flat sandy islet, with a conical heap of coral débris at the southern extremity of the reef flat adjoining it; at the northern end of the flat there are a few negro heads. c and d Reefs are only sand patches (Plates XXXII.–XXXIV.).

For nearly an hour we steamed slowly along the western edge of Cairns Reef, nothing but one mass of negro heads of all sizes, forming a belt along the western edge of the reef flat (Plates XIII., XIV., XV.). The western edge of this reef flat shows perhaps better than any other flat we have examined the belt of dead corals on its surface and the remnants of the old elevated reef on its lee side (Plates XIII., XIV.). On the slopes extending to the main channel, or to the channels separating Cairns Reef flat from the nearest flats, corals were growing abundantly and in large masses and patches close to the upper edge of the flat, rising from six to seven fathoms of water. At less than a cable's length the bottom specimens brought up on the lead were already discolored by admixtures of littoral deposits. On e Reef (South Turtle Reef) we found one to two feet of water; a third of a mile off the northwest side of the centre of the reef we anchored in ten fathoms, muddy bottom.

Coral heads begin to appear on the slope of the reef in from four to five fathoms; in deeper water, the bottom along the slope of the reef is clean coral sand. The slope of the reef is covered with isolated patches

[1] On Plate XXX. Kent has represented the aspect of the surface of one of the reef flats which, as he justly remarks, is in very striking contrast to those coral flats which are only rarely exposed at the lowest tides, and on which corals still flourish in great profusion, and which form the subjects of the many reef views illustrating the "Great Barrier Reef." They are the only Plates which have been published giving an idea of the appearance of a coral reef. Previous writers had only examined as far as they could be observed from the surface the upper belt of growing corals in from seven to ten fathoms and upward, and from their descriptions alone, no matter how vivid, it was impossible to give to the reader who had not seen a coral reef an adequate conception of what a coral reef really looks like. The illustrations of Haeckel in the "Arabische Korallen," while giving an excellent idea of the brilliancy and great variety of coloring in the masses of a coral reef (Plate 3, Arab. Korallen, 1876), are of course not to be compared in their scope with the photographs of Kent.

of corals separated by lanes of clean coral sand. The heads are more numerous between two and three fathoms, decreasing in size and number towards the edge of the reef; in from one and a half to two fathoms, there are found only a few distant patches of corals. As elsewhere, we found among the coral heads magnificent Actiniæ, masses of Alcyonarians and of sponges; as the coral heads grow in less profusion, they also become less abundant; and on the flat of the reef where the coral heads are small and widely scattered Alcyonarians disappear. Actinians are, however, still found between the masses of dead corals which cover the reef flats; here and there we find a small living coral head. The growth on the flat is mainly Algæ and Nullipores. There are fine patches of corals in five fathoms off the northwest end of e Reef.

Negro heads are exposed on one part of the edge, rising perhaps two feet above the general level of the flat. They look to me like fragments of an elevated reef which has been washed away, leaving only here and there an isolated pinnacle, such as we saw so many of on Bramble Reef. It is not probable that they are dead masses of coral thrown up from the present reefs, as there are huge masses of coral growing up all around them.

Passing on to (Ef) f Reef (Plate XXXIII.), we saw at the northeast and east face a long line of negro heads, among them a huge rock about nine feet high, standing fully 250 yards inside of the edge of the reef. It was a mass from a coral head left standing as it grew, but weather and water worn, pitted and honeycombed, and full of boring Mollusks and Annelids, which had made their abode in this huge Porites mass. It was irregular in shape, and black with age, with the general aspect of the coral masses we have been accustomed to find as parts of West Indian elevated reefs.

The southeast face of this reef is flanked by a comparatively broad belt of fine negro heads. The whole surface of the reef flat, wherever we examined it, was covered with larger or smaller fragments of similar negro heads, which had become disintegrated by the action of the sea and worn to their present size. On the parts of the reef flat less exposed to the action of the sea, these fragments were more or less covered with sand, cropping out only here and there in patches, and more or less overgrown with masses of Algæ and Nullipores. On the east face the corals were thriving further in, to the very edge of the reef flat, while on the lee face they were partially overwhelmed with sand. The coral patches on the east face (windward face) of the reef were growing much more luxuriantly than on the other and more sheltered slopes of the reef (Plate XXXIII.).

The coral patches now thriving on the slopes of the reef are growing on the slopes of the former elevated reef, which from its disintegration has formed the extensive reef flats covered with dead corals and flanked with negro heads.[1] The patches of living coral and the heads do not extend to a greater depth than six to seven fathoms. Nowhere at ten fathoms have we found any isolated heads; the bottom at that depth near a coral reef being invariably clean coral sand, with fragments of dead coral. A similar bottom extended into deeper water, and characterized the coral sand lanes separating the coral heads. So that the present reef corals may be said in the upper part of the reef to form a crust over the

[1] I cannot forbear quoting Jukes again at length (Voyage of the "Fly," Vol. I. pp. 340, 341) regarding the negro heads, to show how accurately he noted the existing state of things on one of the great reef flats we have just described. Jukes, in fact, all but named the existence of a former elevated reef as the source from which the negro heads were derived. He writes: "On a reef, forming part of the Great Barrier, about twelve miles southwest of Raine's Islet, I observed a very remarkable, and as far as I know unique fact, which seems to favor the idea of the reef having been slightly elevated in that locality. The mass of reef alluded to is two or three miles long, and from a quarter to half a mile in width. Near its southern extremity, and about fifty yards from its inner edge, there is a range of large coral blocks permanently above water. Immediately to the south of them is a gap or channel of deep water, about a quarter of a mile wide, to the south of which another reef sets on. These blocks are full two hundred yards from the outer edge of the reef, and protected by it from heavy breakers, and it is only at high water that the last curl of surf reaches them through the gap to the southward. No conceivable storm could lift them into their present condition, with the reef around having its present extension. They not only rested on the reef, but appeared to pass downwards into it, as if forming part of its mass. They were composed wholly of a species of Porites, very solid and massive, with comparatively small cells. They seemed to be in the position of growth, with the cells all pointing upwards. The blocks were often as much as twenty or twenty-five feet in length, and rose from the reef to a height of ten or twelve feet; they were very rugged, and apparently much worn, the cells being apparent at the surface in the more sheltered hollows only of the masses. They ran along a line parallel to the inner edge of the reef, for three or four hundred yards. High-water mark was very apparent on them, forming a horizontal line, below which they were much smoother than above it. They ended upwards in sharp points and crags, much honeycombed and excessively rugged. From high-water mark to some of their summits was about eight feet and a sufficiently large mass of them was visible at high water to show like a line of large black rocks, at a distance of two miles. I examined them attentively, and walked about them at low water, and could form no other conjecture respecting them than that they had been produced under water, and raised above it by the elevation of the mass on which they reposed. They looked exactly like the remnants of a much larger mass that had been gradually eaten away and destroyed by the action of the sea and weather."

dead elevated coral reef, which forms the core of the reefs on the dead summit of the reef flats left awash. The slopes of the reef flats are generally very gradual from the edge of the reef left awash at low tide to the clean sand slope found beyond the point at which corals and heads begin to grow. Where the water is deeper than ten fathoms off the reef flat faces, the slopes are usually somewhat steeper, the coral patches and heads rising more vertically from their first appearance, and thus seeming to grow upon a steeper slope.

Our next anchorage was south of the Lark Passage (Plate XXXIII.), on the inside of the outer line of breakers in twenty fathoms, about an eighth of a mile from the narrow reef which forms the southern arc of breakers bounding the Lark Passage. As far as the eye could see, the outer reef formed a series of these arcs slightly overlapping, the shape of which was clearly indicated by the line of huge breakers pounding upon the narrow flat belt of dead corals which separated the outer edge of the reef from the interior passage in which we anchored. This part of the exterior edge of the Great Barrier Reef differs in no way from the inner reef flats we have already examined. As we approach it from the west the coral patches and heads make their appearance in from seven to six fathoms. At first widely separated, then in from five to four fathoms they become more closely connected, and finally form a nearly continuous belt incrusting the inner reef slopes. The growth of coral becomes less and less again as we pass into shallower water, and when we reach the reef flats with two to three feet of water upon it, the corals have become reduced to a few small and scattered heads, the greater part of the reef flat being covered with dead corals and fragments of dead corals upon which Algæ and Nullipores flourish. The width of the reef flat, between the inner line of breakers and the inner edge of the reef flat slope, varied from 200 feet to about 800 feet. Unfortunately, the state of the sea on the outside of the reef was such that it was impossible to examine the condition of the corals growing upon the sea face of this outer reef flat.[1] From what I have been told by

[1] Kent states thirty fathoms to be the limit at which reef corals grow. He must refer to observations beyond the area of the Great Barrier Reef, as he does not state that he has taken soundings to ascertain their lower limit. As far as my own observations are concerned, they are limited to the bathymetrical range of the reef corals on the slopes of inside reefs, or on the lee of the outer line of reefs, and nowhere have I found them, as stated elsewhere in this paper, to reach the limit assigned to them by Kent. I am unable to understand the assertion so frequently made and repeated by Kent and Krämer that the lee faces of a reef show by far the greatest development of living corals. The growth of the reef corals is so fre-

intelligent *bêche de mer* fishermen, they do not think that corals flourish on the outer edge at a greater depth than on the faces of inner reef flats, six to seven fathoms. I have also been assured that the small outer barrier of reef flats which we examined south of the Lark Passage was typical of all the reef flats which form the line of the so called outer linear reefs (Jukes). The surface inside of the breakers of all the outer Barrier Reef flats are covered with dead corals, as those of the interior reef flats are. We may therefore safely conclude that the dead corals which cover the outer reef flats owe their origin to the same cause,— viz. to the disintegration of the former elevated coral reef which once was the outer barrier reef.

That the outer reef flats all are arcs facing the breakers, and form so uniformly narrow shallow strips between deep inner channels and the outer sea-face, we can only explain by the peculiar action of the sea, which invariably on exposed shores erodes islets into a more or less circular outline, and patches into convex faces turned about at right angles to the general trend of the breakers (Plates XXXII.–XXXIV.).

The inner channel of the outside Barrier Reef patches ranges from sixteen to twenty-eight fathoms, the average depth being about twenty fathoms; from this it shoals somewhat steeply to ten fathoms, and then very gradually to the inner edge of the outer reef flats. Between six and seven fathoms coral masses appear, often forming large detached patches rising quite abruptly on all sides to within one or two feet of the surface at low-water mark. From there in on the slope, in four to five fathoms, the patches become more numerous, often forming long connected stretches of coral heads. The belt between five and three or four fathoms is the one in which the corals seem to thrive best. The masses become more or less disconnected again in from one

quently determined by local causes that it seems impossible to assign their great development merely to their position on either the lee or seaward face at any locality. Taking the Samoa Islands, the lee face of the islands is the very face on which the coral reefs of that group are developed. At the Sandwich Islands, where we have the northeast trades, while there is a lee face reef, we have an equally well developed sea-face reef. On the Windward Islands, the sea-face reefs are much more developed than those on the lee face of the islands. On Alacran Reef the lee reef is nearly overwhelmed by the sand driven from the islands over that face, while the sea face is a most flourishing mass of corals. While the lee faces of the Bahamas support a most luxuriant growth of corals, it does not compare with that growing on the weather side. On Hogsty Reef the corals facing the great swell of the northeast trades are far finer than those on the lee side. The same is the case for the Bermudas.

and a half to over two fathoms of water, being separated by lanes of coral sand or by accumulations of fragments of dead corals. On the reef flat proper the coral heads are reduced to diminutive heads, and the greater part of the flats inside of the line of breakers, which carries from four to five feet of water at average low tide, was strewn with fragments and masses of dead corals of all shapes and sizes, much like the condition of things we have seen on the surface of the Turtle Reef flat. They seemed even somewhat more abundant, and the scattered masses and fragments were frequently cemented so as to form a breccia of Madrepores, Astræans, Porites, and the like, incrusted with Nullipores and Algæ. Only here and there on this flat of from 500 to 1,000 feet wide could a few living corals be seen.

A strong current was flowing westward over the reef flat, the result of the back pressure from the mass of water poured over the outer edge of the reef flat by the incessant succession of the huge breakers.

There is no reason for considering the bulk of the dead corals on these outer reef flats or strips as other than the remnants of the disintegrated elevated reef which once covered these strips and the adjoining patches. The process of erosion and disintegration which took place here must have been more rapid, and has of course continued for a greater length of time than in patches more to the westward, — patches which were protected to a great extent by the outer reefs, and did not become exposed to the action of the sea till the outer reef strips had been reduced to nearly the condition in which we find them now. There is every reason to believe that the outer strips of flats now worn to below the level of the sea were at no very distant time (geologically) covered by a reef, which was elevated from ten to twelve feet above the highest level at which corals are now growing. This reef was gradually cut into by the work of the breakers, long water lanes must have crossed the reef flats, and little by little the elevated reef was changed to a series of walls and pinnacles, and as these became eaten away they fell to the ground and were reduced to the smaller fragments of dead corals which now are thickly strewn over the outer reef flats. Where the process has not gone on quite so long a time, as in interior reef flats, we find the pinnacles of coral heads attesting the former greater extent and elevation of the reef; while in stretches still closer to the mainland (as on Middle Island and elsewhere) we still find large patches of the elevated reef which have not been completely eroded or changed into negro heads.

The coral living on the sides of the patches or on the top of the huge heads clearly indicates that this part of the reef when elevated was

not raised beyond low-water mark, while where the surface of some of the large heads is topped with dead coral or with worn masses of the larger species, we may feel reasonably sure that the patch once formed a part of an outlying patch of the elevated reef which has been cut down to its present height by the combined action of the sea and of atmospheric agencies.

We could not fail to notice how rapidly the water became clearer as we steamed eastward toward the outer edge of the Barrier Reef. Both its color and purity were in great contrast to the almost turbid water met with in the channel between the mainland and the most westerly of the inner reef flats, where the silt from the numerous islands and the wash from the mainland is thrown in very large quantities into the sea. But while we could not fail to notice the great contrast in the purity of the water, it may be due to its distance from shore, and perhaps also to its greater depth allowing the silt to subside; for the mud brought up at our anchorage, only a third of a mile from the inner edge of the outer reef flat, was not coral sand, as might have been expected, but mud nearly as dark as that found in the inner more westerly main channels.

Returning to the inner reef patches of this part of the Great Barrier Reef, we find Lark Reef, which forms the southwestern edge of Lark Passage, a huge reef flat differing in no way from the inner reef flats already described, except in the comparative absence of negro heads. The patches on the north of the track to Lark Passage are comparatively small reef patches. On Swinger Reef, a small sand key has been formed on it since the time of the last survey. A sand key will soon be formed on the northern edge of Turtle Key (Plate XXXIII.).

On the east half of Marx's Reef, negro heads occur well on the reef flat itself. Negro heads are also found on the reef flat to the west of Marx's Reef. The only other reef flats we examined were those lying to the westward of the Lizard Islands (Plates XVI., XVII., XXXIV.).

Eagle Islet is a low coral sand islet thrown up from the decomposed beach rock found on the northwestern side of the islet. There is in the extension of the islet a line of sandbars along the edge of Eagle Reef. The summit of Eagle Islet is covered with a little low vegetation. As far as we examined Eagle Reef flat, it appears to be made up of decomposed beach rock sand (Plate XVII.). We could see but few patches of this on the interior of the flat, only here and there an occasional fragment covered with Algæ. Near the edge of the Eagle Reef flat, in from two to three feet of water at low tide, small patches of corals began to make their appearance. The patches rapidly increased

in size, and the corals became quite abundant on the slope of the reef, in about two fathoms of water. Then they formed large disconnected masses separated by lanes of coral sand. These patches and heads continued into five to six fathoms; beyond this we found only clear coral sand. Here, as elsewhere, we brought up from our anchorage, in not more than seven fathoms of water, at a distance of less than half a mile from the bottom of the slope of Eagle Reef, discolored coral sand already well mixed with littoral detritus of a bluish tint. On the east face of Eagle Reef we could distinguish a few negro heads standing out near the outer edge close to the breakers.

The flats of (El) **l** and (Em) **m** Reefs are similar to that of Eagle Reef. There are but few negro heads, and no trace of any beach rock on the sandbars. Their slopes are covered with corals and coral patches, growing under the same conditions as those on the slopes of Eagle Reef. The flats of El and Em Reefs are also quite bare of dead corals, being covered with coral sand, as is the greater part of the Eagle Reef flat.

I have very little to add to the report of Kent on the fauna of the Great Barrier Reef. The collections made during our short visit are naturally insignificant as compared with those made by him during his stay in Queensland. With the exception of the large collection of corals made independently for me by Professor Henry A. Ward, we brought together very little calling for special notice.

The few pelagic tows we made at several points of our route did not give us anything of special interest; the material collected consisting of Copepods, Pteropods, Doliolum, Sagitta, Appendicularia, and a few Medusæ.

At Cairns the same species of Rhizostome we had already seen at Hawksbury River was quite common, only light colored. On our way home, up the Brisbane River, we met the same species in shoals, especially at the bends of the river, where they were packed together like paving stones. The specimens we saw exhibited great variation in their coloring, passing through all the stages possible between light yellow and Prussian blue.

Blue is a very uncommon color among marine animals. A dark blue Linckia is the most common starfish on the inner reef flats. Both it and the black Holothurians so abundant on the reef flats are in glaring contrast to the brilliant yellowish coral sand flats upon which they are found. A similar contrast, and even more striking perhaps, is presented by the large Actinians, fully expanded, and their surroundings on the reef flats, while alongside of the glaring colors are found

yellowish white Holothurians, which it is almost impossible to distinguish from coral sand, and a species of Calappa, of which the markings on the carapace can scarcely be distinguished from the mottled yellow coral sand in which they are partially buried.

The coloring of the coral masses and patches found on the east face of Turtle Reef is most brilliant. Heliopora, huge Alcyonaria of many tints, the pinkish violet Madrepores, large clusters of brown Millepora and Pocillopora, masses of variegated sponges, the brilliantly colored gills of the huge Tridacnas, and the disks of numerous Actiniæ give to the coral patches a brilliancy of color which I have not seen on the most splendidly colored of the West Indian coral reefs.

The preponderance of sponges and Alcyonarians, in place of Gorgonians, is one of the most striking characteristics of the Great Barrier Reef of Australia.

On Dunk Island beach, we found the Balanoglossus described by Hill in Vol. X., Trans. Lin. Soc. of N. S. W., November, 1894.

I may mention here the peculiar patchwork formed by the tracks of a crab over the upper part of the coral sand beach, to the north of the northern breakwater at Townsville. A space fully ninety by twenty feet was completely carpeted with a diagonal pattern of lines of pellets thrown out of the burrows, which gave it very much the appearance of the diagonal tracery so characteristic of Arabic designs, only quite irregular, of course. Unfortunately, the photograph taken of this network of tracks was imperfect.

Jack and Etheridge, in their Geology and Palæontology of Queensland (pp. 614–684),[1] give all the references to the literature regarding the recent elevation of the coast, as shown by the raised beaches occurring at so many points of the coast. Maitland [2] also speaks of the New Guinea terraces (raised beaches?) reaching to a height of 2,000 feet. They very probably represent, as they do in Cuba, elevations which have taken place in different periods.

Speaking of the upper cretaceous formation of Queensland, Jack says (p. 511): "The desert sandstone formation . . . must at one time have covered at least three quarters of the colony of Queensland, — although its denuded remains now occupy less than one twentieth of the area over

[1] It may be that on Raine Islet we also have traces of such an elevated beach. See Rattray, Proc. Geol. Soc. London, 1869, Vol. XXV. p. 303, who, speaking of Raine Islet, says, "It rises ten feet above high-water mark, and consists of hard, compact brecciated conglomerate."

[2] Geological Observations in British New Guinea in 1891.

which it originally extended. . . . After the Rolling Downs formation had been laid down in the comparatively narrow sea which connected the Gulf of Carpentaria with the Great Australian Bight, and converted the Australian area into two islands, a considerable upheaval took place. The denudation of the Rolling Downs formation then followed, and must have gone on for some time. Unequal movements of depression then brought about lacustrine conditions on portions of the now uplifted bottom of the old deep-sea strait, and in other portions permitted the admission of the water of the ocean. Finally a general upheaval placed the deposits of the period just concluded in nearly the position in which we now find them."

Jack considers that "The absence . . . of tertiary marine strata may be due to the fact that the elevation which took place after the deposition of the upper cretaceous rocks (desert sandstone) placed the whole of Queensland above the reach of the ocean during tertiary times." (Geol. and Pal. of Queensland, p. 574.)

These extracts from the past history of Queensland are important, as they clearly indicate the great length of time during which the eastern extension of the Queensland coast has been exposed to the effects of denudation and to the inroads of the sea, — inroads the extent of which is clearly indicated by the islands and archipelagos skirting the northeast edge of Australia, and the extent of the denudation is plainly visible in the shape of the hills and valleys flanking the present coast line.

Jack (Geol. and Pal. of Queensland, p. 613) gives the following proof of a moderate depression of the Queensland coast: "In the neighborhood of Townsville a well reaching to one hundred feet in depth shows the presence of clays and gravel belonging to river beds which fringe the coast from Cape Palmerston to the mouth of Herbert River. No river could possibly have excavated a channel to this depth while the land stood at its present level; it must have been depressed to or beyond the position at which it now stands with reference to the ocean."

Fragments of this lost land, he considers, "remain in Fitzroy, Hinchinbrook, the Palm and Percy Islands, . . . while a submerged range still farther to the east may be represented by the Barrier Reef."

It seems to me that, in addition to the above mentioned submergence of one hundred feet, we must take into account the extensive denudation and erosion which Jack himself has so well described in the paragraphs I have quoted from him. A denudation and erosion which, acting throughout the tertiary period, a period of great fall of water, are of themselves quite sufficient to explain the former connection of the islands off the

Queensland coast with the Australian mainland. The proofs of the moderate subsidence given by Jack only intensify the separation, and furthermore this submergence was followed by an elevation, of which Jack says: "I hold that a great submergence of the eastern coast (as exemplified by Sydney harbor and the Townsville deep drifts) was at a comparatively recent date, succeeded by a movement of elevation which is still in progress."

Steaming through Whitsunday Passage (Plate XXX.) we got our first fine view of the extensive denudation and erosion which has been going on since cretaceous times along the eastern coast of Australia. In the more southern colonies, New South Wales and Victoria, the peculiar valleys of the Blue Mountains and the fine harbors which are found along the coast of the former give an excellent idea of the extent of this denudation.

Moreton Island (Plate XXVI.), the Glassy Mountains, Breaksea Spit, and the passage between Frazer Island and the mainland (Plate XXVII.), are the most southern examples of the formation of islands, the former connection of which with the mainland is still clearly indicated. They are still partially connected, as it were, with the mainland, while to the north the islands, islets, and rocks, which undoubtedly once formed a part of the eastern shore, have become more widely separated. They are in a district in which the erosion and denudation have acted more powerfully.

There is no proof of any extensive subsidence since the cretaceous period, but during that period there must have existed a comparatively deep sea separating that part of Australia which in a general way lies south of the area covered by the desert sandstone formation from the older lands to the north of the present Australian continent. The larger islands are generally nearer the continental shore; as we go out towards the edge of the Barrier Reef they fast become smaller, and near the outer edge of the reef we only find an occasional rocky islet to attest the former existence at from twenty to seventy-five miles from the present shore line of the outer and eastern edge of that continent.

The farther east the more and the longer has the shore line been exposed to the disintegrating action of the sea. Thus the outer islands and islets first separated from the coast were reduced to the level of the sea long before the inner islands now forming the various archipelagos along the eastern coast of Queensland and within the Barrier Reef were separated from the mainland. On the flats thus formed, and on their outer edges, corals began to grow, and as the process of disintegration and erosion extended inland the corals followed in the same direction

until the growth was stopped or greatly diminished by coming into a region such as the Whitsunday Archipelago, where the amount of silt and mud annually washed down the slopes of the mainland and of the islands prevented their successful spreading.

The amount of detritus which is brought down by the Queensland rivers is enormous. The channels of the river harbors, such as Brisbane, Rockhampton, Douglas Harbor, and Cooktown, are constantly being dredged to keep them open for navigation. During the seasons of flood and at other times, this silt is carried a long way off the coast, and materially affects the purity of the water within a considerable distance off shore. Adding to this the wash from the hillsides, it is not astonishing to find comparatively few corals growing close to the shore, and these always more or less affected at certain seasons by the impurities in the water. We may account in this way for the gradual killing of the corals formed in Moreton Bay, and on the northern extremity of the Breaksea Spit, and elsewhere.

It has been stated by most writers on coral reefs that a barrier reef could only be formed in a region of subsidence. But it seems to me that what I have seen of the Great Barrier Reef of Australia leads to no such conclusion, — and it certainly is not the case in Florida. On the contrary, the present condition of the Great Barrier Reef can be satisfactorily explained by the mere action of erosion and of denudation, which has been going on for so long a period along the coast of Queensland. It undoubtedly is the same erosion and denudation which have separated Northern Queensland from New Guinea, and have left the shallow continental shelf which now unites them (Plate XXIV.). Here and there the islands and islets and reefs which stud the whole of that shallow sea attest sufficiently to this former connection, — a connection which existed at the time when the desert sandstone was raised in post-cretaceous times from 2,000 feet or more above the sea level, and has since then been exposed to the most extensive erosion and denudation, — the larger and more numerous islands which extend north of Cape York towards New Guinea, holding to it and to Australia much the same relation which the various archipelagos off the east coast of Queensland once held to the Australian continent.[1] A summary of the geological history of Australia has been given by Mr. A. C. Gregory.[2]

[1] See Rattray, A., Notes on the Geology of Cape York Peninsula, Quart. Jour. Geol. Soc., 1869, Vol. XXV. p. 297.

[2] Proceedings and Transactions of the Royal Geographical Society of Australia, Queensland Branch, Vol. II. Pt. 3, p. 164. Mr. Gregory says: —

The coral reefs found north of Queensland, in Torres Strait, and on both sides of it extending well out toward the 100 fathom line on the east and west, were probably formed much in the same way in which I imagine them to have progressed from the old shore line inland as fast as the land was reduced to the level of the sea.

Darwin and Dana have both assumed, in their discussion of the theory of coral reefs, that the subsidence which they claimed as necessary for the formation of barrier reefs and of atolls took place during the present epoch.[1] It seems to me as if the geological history of Australia throws considerable light on this subject, and that the great subsidence during which the Australian desert sandstone was laid down was perhaps connected with the disappearance of the Pacific continent or archipelago, of which the Australasian Islands are now only the remaining summits; and that denudation of the remnants of this Pacific Island area has been going on apace with that of the Australian coast (Queensland), cutting down the peaks to form huge banks and isolated islets and islands with more or less extensive banks, upon which and on the flanks of which corals have during the present period found their resting place, and have grown to form barrier or fringing reefs and atolls from a comparatively shallow base line, subsidence having played in their formation but an insignificant part.

The unfathomable depth of which we hear so much in all discussions regarding coral reef formations is neither greater nor less than the depths found along any oceanic shore of the same district where

"At the close of the carboniferous period there was a general depression of the whole land to such an extent that all but the higher summits of the more prominent ranges were submerged by the ocean, and only the limits of the future continent indicated by a series of rocky islands extending from Tasmania nearly to Cape York, — the higher lands of southern and western Australia alone escaping. . . . The sedimentary strata of the cretaceous are found abutting on the older rocks, but over the rest of Australia these deposits cover the summits of even the higher ranges. . . . This condition of submergence must have continued until the commencement of the tertiary period. . . . Following this there was a general rise above the ocean, and Australia must have appeared as a continent with nearly its present outline, though the interior probably long retained the condition of a shallow inland sea, communicating with the ocean through Spencer Gulf. The climate was then much moister. Denudation of extensive areas then commenced, leaving only escarpments and table lands to mark the original level of the surface. Only gradually the climate became drier, the lakes were changed to dry plains, and the present condition of things gradually came into existence."

[1] Yet Dana in his "Corals and Coral Reefs" (p. 403), in one instance speaks of the continuity of the coral reefs from earlier periods, if not from the tertiary to the present day.

no corals grow.[1] The sections plotted off the northeastern coast of Queensland indicate a very moderate slope, with the exception of the sudden drop of from ten to twenty fathoms close to the outer edge of the reef, which marks the limits of greatest depth from which corals can build up. Going farther south, the slope in certain localities increases and varies, but neither more nor less than in adjoining localities south of the Great Barrier Reef where there are no corals. Examine, for instance, the sections off Breaksea Spit, off Moreton Island, and then off the coast of New South Wales, which are quite as steep as any of the sections off the Great Barrier Reef, where it is supposed that the great slope is due to the growth of corals during subsidence. (See Plates XXXVII. to XLI.)

A similar state of things exists off the south coast of Cuba, where the slope in a non-coral reef district is steeper than found elsewhere in the coral reef districts of the West Indian area.

The older navigators and explorers have naturally given us but little information regarding the Great Barrier Reef. An interesting sketch, giving a condensed history of these earlier discoveries along the northeast coast of Australia, by Captain W. Thomson, will be found in the Proceedings of the Royal Geographical Society of Australia, Vol. II. Part 3, p. 129.

Flinders is the only one of the early explorers of Australia who not only gave a good description of the Great Barrier Reef, but also speculated on the mode of formation of the coral reefs, and it is interesting to read in his "Terra Australis"[2] the ideas which the older navigators had of the formation of coral reefs: —

"It seems to me that when the animalcules which form the corals at the bottom of the ocean cease to live their structures adhere to each other by virtue

[1] It is interesting to examine what would be the profile of the shore if the present shore line became the edge of the continental plateau. We should find, as at Mt. Thomas, west of the Hope Islands as far as Cape Bedford, a series of soundings ranging from 2,318 feet, say nearly 400 fathoms, at a distance of less than three quarters of a mile from the shore, to 750 feet, separated by level patches. Or again such a bluff as that north of Cooktown, with summits of from 900 to 1,200 feet or more, often at less than half a mile from the coast. I take these elevations merely as an example of the contrast in depths between points within comparatively short distances, which are in every respect similar to depths off the outer edge of the Great Barrier Reef, — depths which are there assumed to indicate the great thickness of the outer edge of the Barrier Reef, while I look upon them merely as the seaward extension of the continental slope of the Australian continent.

[2] Vol. I. p. 115. 1814.

either of the glutinous remains within, or of some property in salt water; and the interstices being gradually filled up with sand and broken pieces of coral washed by the sea, which also adhere, a mass of rock is at length formed. Future races of these animalcules erect their habitation upon the rising bank, and die in their turn, to increase, but principally to elevate, this monument of their wonderful labor. The care taken to work perpendicularly in the early stages would mark a surprising instinct in these diminutive creatures. Their wall of coral, for the most part in situations where the winds are constant, being arrived at the surface, affords a shelter to leeward of which their infant colonies may be safely sent forth: and to this their instinctive foresight it seems to be owing that the windward side of a reef, exposed to the open sea, is generally, if not always, the highest part, and rises perpendicular, sometimes from the depth of 200, and perhaps many more fathoms."

The description which Flinders gives of the appearance of a living coral reef[1] is remarkably graphic and accurate, but he did not, like Chamisso, attempt to formulate a theory of the formation of coral reefs. He was greatly impressed with the beauty and brilliancy of coloring of the corals, and the great variety of their forms. He gives an excellent description of the coral flats covered with dead corals, and of the deep water lanes separating the reef patches. Flinders had also formed an excellent idea of the rôle played by the accumulation of coral débris derived from the outer edge of reef patches in the formation of coral sand islands to the leeward, and their final change from a coral sandbank to an island covered with vegetation. He was also the first to notice the so called negro heads.[2]

It is not until the voyage of the "Fly," from 1842 to 1846, that we have the admirable account of Jukes on the Geology of Queensland and of the adjacent islands, together with a remarkably accurate description of parts of the Great Barrier Reef. The chapter which he devotes to the description of the Great Barrier Reef[3] is by far the best account we have of the Queensland coral reefs.

A number of short notices on the Great Barrier Reef are referred to in Jack and Etheridge's "Geology and Paleontology of Queensland." We have also a few notes on Raine Islet and the vicinity of Cape York in the Narrative of the "Challenger";[4] next, the magnificent volume on the

1 Terra Australis, Vol. II. p. 87.

2 Ibid., p. 83: "The reefs (close to the Percy Islands) were not dry in any part, with the exception of some small black lumps, which at a distance resembled the round heads of Negroes."

3 "Narrative of the Surveying Voyage of H. M. S. 'Fly,'" Vol. I. p. 311. London, 1847.

4 Narrative, Vol. I. p. 528, sheet 27.

Great Barrier Reef by W. Saville Kent;[1] and, finally, a number of references by travellers to the Great Barrier Reef, in which the authors either adopt or reject the theory of subsidence as explanatory of its formation, without however giving any new facts bearing upon the subject.[2]

We need only discuss the views of Jukes and of Kent in the light of the observations made on the "Croydon" during my visit to the Great Barrier Reef.

Jukes's description of the "First Bunker's Island," in the northern part of the Capricorn group,[3] remains to-day an excellent description of a pseudo atoll such as are common on the isolated reef flats of the Great Barrier Reef. Kent copies this as Jukes's description of Lady Elliot Islet.[4] This certainly is a mistake, as the "First Bunker's Island" is in the northern part of the Capricorn group, and "twenty-five miles northwest of Lady Elliot Islet."[5]

Jukes has, it is true, given a sketch of Lady Elliot Islet, but it has nothing to do with his description of "First Bunker's Island." On page 4 he mentions anchoring between "the third or northern Bunker's Island" and "a large coral reef with a shallow lagoon and a small patch of dry sand on its western side." This is probably Boult Reef.

Kent, on p. 106, has copied Jukes's description of "One Tree Island" and of "Heron" Island. Jukes was greatly puzzled regarding the mode of formation of hardened coral rock greatly weathered which forms what subsequent writers have called "beach rock" in coral areas. Jukes speaks of its surface as everywhere rough, honeycombed, and uneven, dipping toward the reef at an angle of 8° or 10°. He has described this beach rock from Heron Island as well as from Wreck Island.

Kent has also reproduced (p. 109) Jukes's account of one of the reefs belonging to the Swain group which Jukes explored, sailing about eighty miles north and south along the eastern edge, and ninety miles right through them in a west-southwest direction, passing through narrow channels from ten to thirty fathoms, the bottom being composed of angular grains of fragments of coral and shells. Jukes was specially

[1] "The Great Barrier Reef of Australia, its Products and Potentialities." London, 1893.

[2] Such as: "Im Australischen Busch und an den Küsten des Korallenmeeres," von Richard Semon. Leipzig, 1896, pp. 273, 345. "Der grosse australische Wallriff," von Albrecht Penck. Wien, 1896.

[3] Voyage of H. M. S. "Fly," Vol. I. p. 1.

[4] The Great Barrier Reef of Australia, p. 101.

[5] Voyage of H. M. S. "Fly," Vol. I. p. 319.

struck with the line of great detached blocks of corals lying a little back from the outer edge of the reef, always quite exposed at low water and not altogether covered even at high tide, and which I consider to be fragments of the elevated coral reef formerly covering the greater part of what are now the reef flats in the district of the Great Barrier Reef.

Jukes was rather disappointed by the aspect of the coral reefs until one day, on the lee side of one of the outer reefs, when the extreme slope was well exposed and when every coral was in full life and luxuriance. This feeling of disappointment is very natural, for there is no coral district like the Great Barrier Reef, where there are such extensive reef flats bare or nearly bare at low water covered with dead coral débris, on the slopes of which or on the deeper flats alone are found live corals extending into seven or more fathoms, the belt nearest the upper edge of the flats not being usually very thriving, or indistinctly visible from the wash of the sea, or not exposed at a particular stage of tide.

Jukes noticed that corals could remain alive even after having been exposed to the action of the atmosphere for a considerable length of time. He says (page 119): "I observed to-day that some considerable portions of coral, all alive and colored, were left by the tide six or eight inches above the water, and remained so for nearly an hour. . . . I often observed the same fact both before and since, and believe that an exposure of two or three hours to the air and the sun will not kill many of the coral polyps. . . . I have seen blocks of living Astræa with the green animals in their cells, the top of which was eighteen inches above the water."

As Kent has well stated, in a district like that of the Great Barrier Reef, where the tidal extremes are considerable, it is natural that even those who are most familiar with the fisheries off the coast of Queensland should not have seen the coral reefs laid bare at the proper time of tides. Kent's superb photographs leave one no doubts as to the aspect of extensive stretches of live coral reefs when exposed by the tide. But an examination of the photographs accompanying this sketch of the Great Barrier Reef will also leave the reader in little doubt as to the uninteresting condition of the reef flats covered with dead corals and coral débris.

In the West Indian district the differences of the tides are slight, and it is rare when any extensive tract of live corals is laid bare by the receding tides. Only twice during the frequent and prolonged visits I have made to the Florida Reefs has it been my fortune at the Tortugas to see extensive tracts of Madrepores exposed for a while to the action of

the air and sun. In both instances the exposure was due to the force of the gale at low tide driving the water off the flats upon which the Madrepores were growing. On a later occasion, a similar gale lasting longer completely destroyed this field of Madrepores.

During a visit which I paid to the Bermudas, the extensive reef patches covered with living corals within the outer lagoons were exposed at an extremely low stage of tide during the time we were steaming out of the Bermudas on our way to New York. It is very evident that in those coral reef regions of the Pacific where there is a great range in the rise and fall of tide, it is not unusual to have great stretches of coral reef exposed at low tides, if we may judge from the photographs of a coral reef exposed on the weather side of Levuka (Fiji Islands) which is on exhibition in the coral gallery of the British Museum, from similar photographs from the Hebrides in the coral gallery of the American Museum of Natural History in New York, and from a photograph of a Madrepore reef on the lee side of Apia published by Krämer.[1]

The description which is given by Jukes (Voyage of the "Fly," Vol. I. p. 314) of one of the reef flats of the Great Barrier Reef is a most admirable description of the average reef flat characteristic of the Australian coral belt. As Kent has not reprinted this account, I here reproduce his description of what I have called a "reef flat or reef patch": —

"The size and form of an 'individual coral reef' is perfectly indeterminate; it may be circular, oval, or linear; its surface may vary from a mere point to an area of many square miles. Those, however, which occupy the extreme edge of a mass of reefs (there is a term wanted to express the distinction between an individual reef, unbroken by any deep water channel, and a group of such reefs. For the latter I am almost tempted to use the word 'reefery'; for the former I have, in this passage, used the expression 'individual coral reef'), or rise on one side from great depths, having on the other comparatively shallow water, have generally a linear form, being three, five, or ten miles long, and varying in breadth from one or two hundred yards to perhaps a mile. This seems to be more especially the case when their direction runs across that of the prevailing wind. The individual coral reefs which rise from an equal

[1] Ueber den Bau der Korallenriffe und die Planktonvertheilung an den Samoanischen Küsten, von Dr. Augustin Krämer, Kiel, 1897, p. 65. On the preceding page Krämer has figured the reef flats to the eastward of the entrance of Apia covered with coral débris which resemble the uninteresting reef flats of the Great Barrier Reef, and which I had an opportunity of examining when at Apia. See also A. Agassiz, The Coral Reefs of the Hawaiian Islands, Plates VIII., IX., Bull. M. C. Z., Vol. XVII. No. 3, 1889.

depth all round, whether that depth be great or small, are more commonly of an oval, circular, or irregular shape, but these are usually much larger when exposed to the wind and surf than in more sheltered situations.

"To get an idea of the nature and structure of an individual coral reef, let the reader fancy to himself a great submarine mound of rock, composed of the fragments and detritus of corals and shells, compacted together into a soft spongy sort of stone. The greater part of the surface of this mound is quite flat and near the level of low water. At its edges it is commonly a little rounded off, or slopes gradually down to a depth of two, three, or four fathoms, and then pitches suddenly down with a very rapid slope into deep water, 20 or 200 fathoms, as the case may be. The surface of this reef, when exposed, looks like a great flat of sandstone with a few loose slabs lying about, or here and there an accumulation of dead broken coral branches, or a bank of dazzling white sand. It is, however, checkered with holes and hollows more or less deep, in which small living corals are growing; or has, perhaps, a large portion that is always covered by two or three feet of water at the lowest tides, and here are fields of corals, either clumps of branching madrepores, or round stools and blocks of mæandrina and astræa, both dead and living. Proceeding from this central flat towards the edge, living corals become more and more abundant. As we get towards the windward side, we of course encounter the surf of the breakers long before we can reach the extreme verge of the reef, and among these breakers we see immense blocks, often two or three yards (and sometimes much more) in diameter, lying loose upon the reef. These are sometimes within reach by a little wading; and though in some instances they are found to consist of several kinds of corals matted together, they are more often found to be large individual masses of species, which are either not found elsewhere, and consequently never seen alive, (I have seen a block of mæandrina of irregular shape, twelve or fifteen feet in diameter, the furrows of which, though much worn and nearly obliterated, were wider than my three fingers; also very large blocks and crags of a porites, twenty feet long and ten feet high, but all one connected mass, without any breaks in its growth,) or which greatly surpass their brethren on other parts of the reef in size and importance. If we approach the lee edge of the reef, either by wading or in a boat, we find it covered with living corals, commonly mæandrina, astræa, and madrepore, in about equal abundance, all glowing with rich colors, bristling with branches, or studded with great knobs and blocks. When the edge of the reef is very steep, it has sometimes overhanging ledges, and is generally indented by narrow winding channels and deep holes, leading into dark hollows and cavities where nothing can be seen. When the slope is more gentle, the great groups of living corals and intervening spaces of white sand can be still discerned through the clear water to a depth of forty or fifty feet, beyond which the water recovers its usual deep blue.[1]

[1] Jukes (p. 11, *loc. cit.*) says he could distinguish the bottom as deep as seven fathoms, but in ten fathoms the depth of color can scarcely be distinguished from the dark azure of the unfathomable ocean. He also states that a shoal with even five

A coral reef, therefore, is a mass of brute matter, living only at its outer surface, and chiefly on its lateral slopes. It is believed that coral animals cannot live at a great depth; that twenty, or at most thirty fathoms, is their extreme limit of growth. This is apparently proved, or nearly so, with respect to all *known* species of coral that form reefs, all those found in the hollows or on the sheltered slopes of reefs, where alone they can be examined. Whether it be universally true, for all polyps depositing large masses of calcareous matter, will perhaps admit of a doubt."

Juke's account of the impressions produced by a visit to the outer line of reefs is well worth repeating: —

"Anchored under the lee of a sandbank [Barrier Reef entrance, near Cape Melville], on which I was able to land. This reef was about two miles long, and one mile broad. . . . The sand was wholly calcareous, grains of triturated corals and shells. . . . The outside edge of the reef was of course unapproachable, but the inside I examined as we passed it. The reef sloped gradually at its edge, from a depth of one or two feet to about four fathoms. . . . At this depth the white sandy patches at the bottom could be distinctly seen among the large dark masses of living coral. Immediately beyond this the lead sank to ten fathoms. . . . The sand banks are invariably on the lee side of the reef they are upon, which shows the nature of their origin."[1]

Jukes paid a visit to the wreck of the "Martha Ridgway," which lay on the outer Barrier Reef off Raine Islet. Of this visit he says: —

"The long ocean swell being suddenly impeded by this barrier [the outer line of the Barrier Reef] lifted itself in one great continuous ridge of deep blue water, which, curling over, fell on the edge of the reef in an unbroken cataract of dazzling white foam. Each line of breaker was often one or two miles in length, with not a perceptible gap in its continuity. After recovering from this leap, and spreading for some distance in a broad sheet of foam, the wave gradually swelled again into another furious breaker of almost equal height and extent with the first, and then into a third, which, although much less considerable, yet thundered against the bows of the wreck with a strength that often made her every timber quiver. Even then the force of the swell was not wholly expended, two or three heavy lines of ripple continually traversing the reef, and breaking here and there against the knobs and blocks of coral that rose higher than usual. There was a simple grandeur and display of power and beauty in this scene, as

fathoms water on it can be discerned at a mile distance from a ship's masthead, in consequence of its greenish hue contrasting with the blue deep water. In seven fathoms water the bottom can still be discerned on looking over the side of a boat, especially if it have patches of light-colored sand. But, as I have already stated elsewhere, with a water glass it is possible to obtain excellent views of the bottom at somewhat greater depths.

[1] Voyage of the "Fly," Vol. I. p. 103.

viewed from the forecastle of the wreck (about thirty feet above the water) that rose even to sublimity. The unbroken roar of the surf, with its regular pulsation of thunder, as each succeeding swell first fell on the outer edge of the reef, was almost deafening, yet so deep-toned as not to interfere with the slightest nearer and sharper sound, or oblige us to raise our voices in the least. Both the sound and the sight were such as to impress the mind of the spectator with the consciousness of standing in the presence of an overwhelming majesty and power, while his senses were delighted by the contrast of beautiful colors afforded by the deep blue of the ocean, the dazzling white of the surf, and the bright green of the shoal water on the reef.

"The reef, when closely examined, appeared to consist of a sandy floor, on which were thickly clustered clumps of coral, scattered closely but irregularly about it. The corals appeared principally rounded masses of astræa and mæandrina, covered with their green-colored animals in a state of expansion; there were, however, many finger-shaped madrepores of beautiful purple colors, and leaf-like expansions of explanaria and other branching corals. These were now generally covered with from one to four feet of water, but some masses were level with its surface. The whole was checkered with spaces of white sand, had a bright grass-green hue when viewed from a distance, and, when looking down on it from the poop of the wreck, might have been likened to a great submarine cabbage garden."[1]

Very little can be added to the sketch of the Barrier Reef given by Jukes in Chapter XIII. of the Voyage of the "Fly," beginning at Sandy Cape and extending northward into Torres Strait (pp. 318 to 332), and including an account of the detached reefs off the Great Barrier Reef. Jukes gives a detailed description of Raine Island, which has been reprinted by Kent,[2] and comes to the conclusion that in Torres Strait there is a band of islands to the westward of the coral reef, which, with the exception of the narrow fringing reefs round the islands, are composed of rocks similar to those of the east coast of Australia, extending across to New Guinea, while these rocks are not found upon the islands to the east of the reefs.

While it is undoubtedly true, as mentioned by Kent, that Jukes considered Darwin's hypothesis as "perfectly satisfactory to my [his] mind,"[3] yet I cannot help analyzing Jukes's summary to show how correctly he had analyzed the main features of the Great Barrier Reef, and of its relations to the mainland and intervening islands, and was led to what seem to me erroneous conclusions, from the inferences he drew from the

[1] Voyage of the "Fly," Vol. I. p. 121.
[2] Great Barrier Reef, p. 118.
[3] Voyage of the "Fly," Vol. I. p. 347

diagram he gives of an imaginary section of the Great Barrier Reef, and which I here reproduce.[1]

JUKES'S SECTION ACROSS THE GREAT BARRIER REEF.

a. Sea outside the barrier, generally unfathomable.
b. The actual barrier.
c. Clear channel inside the barrier, generally about 15 or 20 fathoms deep.
d. The inner reef.
e. Shoal channel between the inner reef and the shore.
F. The great buttress of calcareous rock, formed of coral and the detritus of corals and shells.
G. The mainland, formed of granites and other similar rocks.

It seems strange that Jukes should have given a section across the Great Barrier Reef, and have left out the islands which crop out nearly all along the coast of Queensland between the mainland and the outer or inner line of reefs. This would have given his section an entirely different aspect, as he would have had, cropping up and connected with the line of the mainland, a series of peaks rising from ten to thirty fathoms, round which alone, or round the flat bases of islands and peaks which had disappeared from erosion or other atmospheric causes, corals had grown. Such a section is not an imaginary one, for the channels between the outcropping peaks, islands, reefs, or reef flats are covered with the telluric detritus derived from the decomposition of the rocks forming those islands, or obtained from the slopes of the mainland. Such a section would have shown the layer of corals to be comparatively thin, of not more than twelve to fifteen fathoms, and it would have shown the great probability that the outer line of reefs, even built upon similar bases, once connected with the mainland, had not attained a much greater thickness. See sections across the Great Barrier Reef, Plates XXXVII. to XLI. That Jukes himself felt his imaginary section and his explanation of it not to be of universal application can be proved from his own words.[2] He says: —

[1] Voyage of the "Fly," Vol. I. p. 333. [2] Ibid.

"The most remarkable deviations from this condition are in the spaces between Cape Melville and Lizard Island, and at the back of Wreck Bay and Raine's Islet. Now in each of these cases there are islands of granite or other rocks advanced from the mainland, and thus causing an original irregularity in the depth of water, as it would be independent of the coral reef. This is very remarkable in the space between 12° 20′ and 11° 30′, where we have Cape Grenville, Cockburn Islands, and Sir C. Hardy's Islands, projecting towards Raine's Islet opening, and Fair Cape and Cape Weymouth, with Forbes Island and Quoin Island projecting towards Wreck Bay. Near Sir Charles Hardy's Islands there is also a remarkable narrow channel of deep water, between them and the large Cockburn reef, in which there is a depth of thirty fathoms, while on each side of it is either a reef nearly dry at low water, or a depth not exceeding ten fathoms. This channel is about twenty miles long, rarely more than two miles broad, and it runs in the same direction as the islands lie off Cape Grenville, or about east-northeast, and points in a straight line for Raine's Islet opening."

It seems to me that Jukes has here struck the correct explanation of the structure of the Great Barrier Reef. But having examined only the two extremes, he did not perhaps realize that the same condition of things existed off any line in which such islands were found. He allowed his admiration for the simplicity of the explanation of the theory of coral reefs by Darwin to blind him to his own still simpler explanation, which I will here quote.[1]

"In the first place, speaking generally, the outline of the Great Barrier Reef is parallel to the outline of the northeast coast. The one follows the other in all its curves and flexures with quite sufficient conformability to show that the two are connected. This is perceptible even in the small chart attached to this work, but still more remarkably so when the large Admiralty Charts are examined. It is evident that the circumstances that modified the outline of the coast likewise determined the general outline of the reefs. This is nothing else than to say, that the outline of the reefs depends upon the depth of the water. Just as in a large and accurate chart of any line of coast we should find the boundary of any certain line of soundings, such as 20, 50, or 100 fathoms, conforming generally to the outline of the coast, following its larger flexures and more important features ; so we find the outline of the Barrier Reefs conforming to the northeast coast of Australia. Granting that the mean slope of the rocks, forming the original sea-bottom of this coast, was tolerably regular and conformable to the slope of the land, it is evident that if we took away the coral reefs and raised the land to any given height, as, for instance, 100 fathoms, we should not greatly alter the outline of the coast, but only shift its situation. It would be thrown so much further for-

[1] Voyage of the "Fly," Vol. I. p. 345.

ward, or towards the east. Now suppose the coast cleared of coral reef, and raised so much that it emerged from the sea just within the line of the present Barrier Reef. Then let the reef commence in the shallow water along that shore, and a very slow and gradual depression take place, giving time for the polyps to build up so as to keep near the surface of the water. The result of this action would be the present Barrier with its steep outer slope, and its gradual extension over the sinking rocks that were once dry land within it. Portions that were once hills on the dry land would now be islands between the Barrier and the main, such as Sir C. Hardy's Island and those about it. Islands that once existed in front of the mainland would now be altogether submerged, and their places only marked by detached reefs outside the Barrier, such as those north and south of Wreck Bay. According to the old rule of high land and deep water going together (in other words, the slope of the ground below water being only a continuation of that above), we should have the Barrier much closer to the present land in its more abrupt and lofty portions than in those which were lower and less highly inclined. We see accordingly the reefs approach the present land about Cape Melville, where the land is steep and lofty, and recede from it as we go further north in proportion as the land becomes flatter and more gentle in its inclination. Deep holes and ravines, full perhaps of fresh water, may have existed on the old land, so that when the surface of these lakes and hollows first sank to the surface of the sea, and admitted its waters, the bottom may have been too deep for the coral animals to live on. This would explain such a phenomenon as the deep narrow channel just north of Sir C. Hardy's Islands, with reefs running along each side of it. In short, every modification in the form and structure of the reefs is explicable by this hypothesis, and many difficulties solved, which admit of no other explanation."

He assumes, as we do, that the Australian coast at one time was just within the line of the present Barrier Reef; but it seems to me that the causes given by Jukes for the formation of the Barrier Reef are equally well explained by erosion and denudation. He assumes a great thickness for the corals on the outer edge of the Barrier Reef, — a thickness to have grown by the synchronism of the subsidence and the growth of the corals, — a thickness the extent of which no one can even guess at. We assume for the corals a thickness that can be determined fairly accurately as only a veneer of at most twenty fathoms upon the faces of the denuded platforms of the islands which once formed the outer line of the Australian continent, the remnants of which are still left as monuments of such a connection in the numerous islands scattered along the whole length of the Queensland coast, at various distances between the mainland and the line of reefs forming the outer edge of the Great Barrier Reef. The geological structure of these

islands plainly indicates their former connection with the Australian continent.

It may not be out of place to examine now what light the hydrography of Queensland throws upon the subject of the extension of the rocks of the mainland to the outer edge of the Great Barrier Reef. To elucidate this point I have prepared a series of sections taken from the Admiralty Charts, extending from Moreton Bay to New Guinea (Plates XXIII., XXIV., XXXVII. to XLI.).

The continental plateau off the east coast of Australia is a comparatively narrow shelf, varying in width north of Sydney between fifteen and thirty miles, which is the distance at which we find the 100 fathom line, and where the slope becomes most abrupt, depths of 1,500 to over 2,000 fathoms are reached within short distances. The continental plateau widens somewhat to the east of the Capricorn Channel (Plate XXXVII. Fig. 6), where it attains a width (its greatest width) of nearly 150 miles. The outer edge then runs in a westerly direction, gradually coming nearer the mainland (Plate XXXVIII.), to Flinders Pass, where it is less than forty miles distant from the mainland.

The outer edge of the Barrier Reef there takes a more northerly direction, gradually approaching still more the continental shore, and in some places not being more than twelve to fifteen miles from it (Plate XXXIX., Plate XL. Figs. 18–22); until somewhat south of Cape Grenville, the outer edge of the Great Barrier Reef runs due north and expands into the wide continental platform, from 100 to 110 miles, which unites the Australian continent with New Guinea (Plate XL. Figs. 23–26, Plate XLI.).

An inspection of the charts and of the sections cannot fail to show that the pitch of the narrow continental shelf off the east shore of Australia south of Sandy Cape (Breaksea Spit) is much steeper than the sea slope of the continental shelf north of it. With the exception of a short distance parallel to the outer edge of the Great Barrier Reef and extending from Lark Pass to off Cape Melville, the 1,000 fathom line is close to the 100 fathom line south of Breaksea Spit to well beyond Sydney; while north of Sandy Cape, with the exception named above, the 1,000 fathom line forms a great loop to the eastward, and is often 250 miles distant from the 100 fathom line. So that, in the very region where the Great Barrier Reef extends, the continental slope does not compare in steepness to the pitch which characterizes it in the non-coralliferous belt to the south of Frazer Island. (Compare the different figures of Plate XXXVII.)

There is nothing to show that the slope of the continental plateau has been modified by the growth of the Great Barrier Reef, and that we have a steep pitch (almost a vertical rise, due to the growth of corals) from unfathomable depths to the edge on the sea-face of the living Great Barrier Reef. On the contrary, the steepest slope of the continental shelf off the Australian continent is in the region south of the Great Barrier district.

On examination of the sections on Plates XXXVII. to XLI., it will be seen that they consist of two distinct types. One of these corresponds in a general way to the imaginary section given by Jukes; such as Plate XXXVII. Figs. 4, 7; Plate XXXIX. Figs. 13, 15; Plate XL. Figs. 19, 22. The other type is radically different, and is inconsistent with the existence of a coral reef rock extending from the outer barrier reef to the shore of the mainland; it is represented by such sections as Plate XXXVIII. Figs. 8–10, Plate XXXIX. Fig. 16, and Plate XL. Figs. 21, 24, 25, in which islands of considerable height similar in geological structure to that of the mainland protrude along the line of the section, clearly indicating that the continental slope extends from the mainland out to the edge of the Barrier Reef, and is only covered by a limited depth of coral reef rock, or by telluric deposits derived from the disintegration of the rocks on the slopes of the mainland and of the outlying islands.

In the one case, the sections have been made across a region in which the islands once existing off the mainland have been eroded and denuded and levelled off into flats, now covered with coral reefs, while in the other case the sections have been made across a district in which the islands, while they have undoubtedly been greatly worn, yet remain sufficiently high to show their former connection with the continental area.

Perhaps no two sections indicate this contrast more markedly than the western section through Torres Strait (Fig. 28 on Plate XLI.) across the line of islands and reefs extending from the mainland to New Guinea, and the section more to the eastward from Mount Adolphus to Dane Road in New Guinea, (Plate XLI. Fig. 27,) cutting only reef flats which owe their existence to the extensive denudation of the lower islands which once formed a line of hills reaching across that part of Torres Strait on the plateau formerly connecting Australia and New Guinea.

An examination of the sections along the passes through the Great Barrier Reef, (Plate XXXVII. Fig. 5, Plate XXXVIII. Figs. 10, 12, Plate XXXIX. Fig. 17, Plate XL. Figs. 20, 23, 24, 26,) show a very

gradual pitch in the continental slope, and there is nothing to indicate that the outer Barrier Reef patches rise from very great ("unfathomable") depths. On the contrary, the outer reef patches are all well within the 100 fathom line, and at a distance from it, except where the pitch of the continental slope is unusually steep. The inner reef patches all come up from a line which cannot be of greater depth than about twenty fathoms, that being the average depth of the first inner channel between the outer patches of the Barrier Reef and the outer line of inner reef flats. The inner line of reef flats rises from a lesser depth, not more than ten to fifteen fathoms. The section lines passing from the mainland to the line of outer barrier reef, across high rocky islands and reef flats, indicates that the coral reef rock and coral reefs can only constitute a comparatively thin sheet from the outer line of inner reef flats towards the mainland, and that this sheet probably does not extend beyond the lower slope of the islands which they surround, and the base of which is formed by the submarine extension eastward of the strata of the continental slopes. And furthermore that the outer barrier reef probably does not rise from a much greater depth than that at which reef-building corals can flourish.

Kent has followed very much the same line of argument as Jukes, in assigning the formation of the Great Barrier Reef to the depression (in recent times) of the northern part of the Australian continent, — a depression, however, which must have taken place during cretaceous times. But he lays no stress on the connection which must have existed in comparatively recent times between Australia and New Guinea, during the early part of the formation of the Great Barrier Reef, — a connection fully recognized by Jukes,[1] who seems to have been most successful in applying the principles of Edward Forbes in the distribution of the British Fauna and Flora to those of Australia and New Guinea.

It is interesting to note that Jukes, while convinced that the northeast

[1] Voyage of the "Fly," Vol. I. p. 347. Jukes writes: "It follows that, during the early part of the period of their formation, Torres Strait, and the shoal seas on each side of it, were dry land, and Australia connected to New Guinea.' This would explain, perhaps, the fact of the marsupial type of animals being common to both, though the genera and species are different. It would explain also the difference in the assemblage of shells, etc., on the northern and southern sides of Torres Strait mentioned before, page 229, as each group would spread into the newly formed sea from the nearest adjacent shores, the Molucca group coming from the north, and the Australian from the south. The existing vegetation of the two countries would seem to have originated, or at least to have spread over their opposite shores since their separation."

coast of Australia had "not suffered *any depression* during a long period of time," yet considered this no valid objection to Darwin's theory, "because previously to this time depression might have been taking place throughout a far more extensive period." This statement seems to me to open a totally different question from that originally considered by Darwin. We are now called upon to decide upon the continuity of the coral reefs of to-day with reefs which must have had their origin within the tertiary period. If this continuity has existed, the reefs of the tertiary period, as far as we know them from their fossil representatives, differed greatly from the reefs of the present epoch, which Jukes has characterized as "the coral age of the globe."[1]

That such a depression as is required by the Darwinian theory of coral reefs has actually taken place over the greater part of Northeastern Australia, no geologist will deny. But it is a depression which dates back to the cretaceous period, and surely we cannot claim that the corals which underlie the Great Barrier Reef of to-day began to grow along the cretaceous shores of Northeastern Australia at the time when this great depression began, and that they have a thickness which should correspond to a depression of at least 2,000 feet. There is nothing in the known configuration of the coast of Queensland, as shown by the hydrography, to warrant such an inference.

Krämer[2] has also pointed out the irrelevance of introducing questions of secular elevation or depression into the discussion of the formation of coral reefs. His review of the subject, as far as it relates to the coral reefs of the Samoa Islands, is on entirely different lines from the discussion of the theory of Kent, who was writing in great part in a popular manner, and often adopted arguments which he must have expected his readers "of necessity to skip."[3] That the theory of subsidence to ac-

[1] Voyage of the "Fly," Vol. I. p. 343, and Murray, John, Trans. R. S. Ed., XXXVIII. No. 10, p. 491.

[2] Ueber den Bau der Korallenriffe, p. 36. See also A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XVII. No. 3, 1889, p. 131.

[3] It is unfortunate that in his general discussion of the theory of coral reefs Kent should not have been more accurate, and have revised the statements of the older writers he quotes, in the light of the more recent publications on coral reefs. We certainly know enough of the topography of the Marshall and Caroline Islands to show the inaccuracy of the following statement: "The respective superficial areas of the Low, Marshall, Caroline, and Maldive archipelagos, none of which contains an islet which rises above the height to which waves and wind or open sea can heap up matter." The statements of Darwin regarding atolls of the West Indies, and the characteristics of some of the banks in the same district, which Darwin obtained at second hand, are repeated again, although enough has been written on the West Indian coral reefs to show what these banks and atolls really are.

count for the formation of the Great Barrier Reef has been received as an elementary axiom in the "leading Australian handbooks," is surely no evidence that the theory is correct, as Kent seems to imply. Nor is the separation of New Guinea from Australia in the middle tertiary a proof that the existing coral reefs of the Torres Strait began to grow at that period, nor does the fact that the marine areas of Australia have undergone "a vast movement of subsidence" (during the cretaceous period) have any bearing on the subsidence needed in our own epoch to account for the formation of reefs. Kent sums up his views as follows: "The foregoing geological evidence [of subsidence in tertiary and cretaceous times] being trustworthy and true, the construction of the Great Barrier Reef of Australia under conditions of subsidence, and in accordance with the original hypothesis of Mr. Darwin, is proved." A statement from which we beg to differ *in toto*, for the reasons set forth in this account of the Great Barrier Reef.

Cambridge, September 1, 1897.

NOTICE.

This Bulletin has been in type since last September. Owing to my absence in Fiji, its publication has been delayed to the present time.

Alexander Agassiz.

Museum of Comparative Zoölogy, Cambridge, Mass.,
March 29, 1898.

EXPLANATION OF THE PLATES.

PLATE I.

Northwestern Point of Middle Island (Edgecombe Bay) seen from the North. Mainland in distance (Cape Gloucester).

PLATE II.

Shore Edge of Flat off the southwestern part of Middle Island, low water.

PLATE III.

Eastern part of Middle Island; Flat to the south of the Island, and pile of Coral Débris.

PLATE IV.

Coral Conglomerate on the shore of Middle Island.

PLATE V.

b Reef (off Endeavour Reef) from the eastward.

PLATE VI.

Flat off the southern point of the most eastern of the Hope Islands.

PLATE VII.

Three Isles, northern extremity.

PLATE VIII.

Beach on the east side of Three Isles.

PLATE IX.

Negro Heads off the east side of Three Isles.

PLATE X.

Elevated reef rock, Lagoon side of Three Isles.

PLATE XI.

Three Isles Lagoon.

PLATE XII.

Northern extremity of Bramble Reef (not uncovered).

PLATE XIII.

The Negro Heads of the western edge of Cairns Reef, low water.

PLATE XIV.

Another part of the western edge of Cairns Reef.

PLATE XV.

Southwestern extremity of Cairns Reef.

PLATE XVI.

Eastern shore of Eagle Reef. The Lizards in the distance.

PLATE XVII.

Western shore of Eagle Reef. Beach Rock.

PLATE XVIII.

Langford Island, with reef to the south. Mainland in distance.

PLATE XIX.

Orpheus and North Palm Islands (Mainland behind). Hinchinbrook Island in the background.

PLATE XX.

Southwest end of Fitzroy Island.

PLATE XXI.

Southwest end of Lizard Island.

PLATE XXII.

Northeast end of Lizard Island.

PLATE XXIII.

Coast of Queensland from Great Sandy Island to Trinity Opening.
Admiralty Chart No. 2763.

PLATE XXIV.

Coast of Queensland from Cape Grafton to New Guinea.
Admiralty Chart No. 2764.

PLATE XXV.

Eastern extremity of New Guinea with Louisiade Archipelago.
Admiralty Chart No. 2764.

PLATE XXVI.

Moreton Bay. Admiralty Chart No. 1670.

PLATE XXVII.

Wide Bay, Great Sandy Island, Hervey Bay. Admiralty Chart No. 1068.

PLATE XXVIII.

Bustard Bay, Capricorn Group, Keppel Bay. Admiralty Chart No. 345.

PLATE XXIX.

Cape Townshend, Percy and Northumberland Islands. Admiralty Chart No. 346

PLATE XXX.

Cumberland Islands, Whitsunday Islands and Channel.
Admiralty Chart No. 347.

PLATE XXX.[a]

Palm Islands, Hinchinbrook, Dunk Island. Admiralty Chart No. 2349.

PLATE XXXI.

Cooper Point to Fort Douglass, Flora Pass, Grafton and Trinity Openings.
Admiralty Chart No. 2350.

PLATE XXXII.

Hope Islands to Indian Head. Admiralty Chart No. 2923.

PLATE XXXIII.

Cape Bedford to Cape Flattery. Admiralty Chart No. 2923.

PLATE XXXIV.

Cape Flattery, Lizard Islands. Admiralty Chart No. 2923.

PLATE XXXV.

Torres Strait. Admiralty Chart No. 2375.

PLATE XXXVI.

Torres Strait. Eastern System of Reefs. Admiralty Chart No. 2422.

PLATES XXXVII. to XLI.

Sections across the Great Barrier Reef, taken from Admiralty Charts.

PLATE XXXVII.

Fig. 1. From Elliot River across Hervey Bay and beyond the Continental Slope.
" 2. From Burnett River across Breaksea Spit.
" 3. From Kolan River to Lady Elliot Islet and beyond.
" 4. From Curtis Island through Masthead Island, One Tree Island, and beyond.
" 5. From Port Bowen across the Capricorn Channel.
" 6. From Port Bowen across Swain Reef to Saumarez Reef and beyond.
" 7. From Broad Sound across the outer Barrier Reef to Marion Reef.

PLATE XXXVIII.

Fig. 8. From Point Molle across Whitsunday Island to the Barrier Reef.
" 9. From Townsville across the Barrier Reef to Flinders Reef.
" 10. From Halifax Bay across the Palm Islands to Palm Passage.
" 11. From Cape Grafton to Holmes Reef.
" 12. From Cape Grafton to Grafton Passage.

PLATE XXXIX.

Fig. 13. From the Mainland across the Hope Islands, Cairns Reef, and Turtle Reef, to the outer Barrier Reef.
" 14. From Swinger Reef to Lark Passage.
" 15. From the Mainland through Wooded Isle, the Three Isles, to the outer Barrier Reef.
" 16. From Lookout Point to the outer Barrier Reef.
" 17. From Lizard Island to Cormorant Pass.

PLATE XL.

Fig. 18. From Cape Flattery to South Direction Island.
" 19. From Brown Peak across Cole Island and Howick Island, to the outer Barrier Reef.
" 20. From Cape Melville to Melville Pass.
" 21. From Bathurst Point to the outer Barrier Reef.
" 22. From Cape Bowen through Bewick Island to the outer Barrier Reef.
" 23. From Cape Grenville through the Blackwood Channel towards the Great Detached Reef.
" 24. From the Murray Islands in the direction of Flinders Entrance.
" 25. From Orman's Reef in the direction of Flinders Entrance.
" 26. From North Warrior Reef to the north end of Flinders Entrance.

PLATE XLI.

Fig. 27. From Mount Adolphus to New Guinea.
" 28. From the Mainland to Orman's Reef.

B. Meisel lith.

B. Meisel lith.

B. Meisel, lith

B. Meisel lith.

AGASSIZ GREAT BARRIER REEF. PL. XXVIII

B Meisel lith

B Meisel lith

B. Meisel lith

1.
Elliot River
Hervey Bay
Break Sea Spit 320 ft.
Sea Level
2.
Burnett River
Break Sea Spit
30 Miles
Sea Level
3.
Double Sloping Hill 1440 ft.
Kolan River
Lady Elliot Id.
30 Miles
Sea Level
4.
Curtis Id. 450 ft.
Mast Head Id.
One Tree Id.
30 Miles
3 m. south.
5.
1012 ft.
Port Bowen
30 Miles
Capricorn Channel
Sea Level
6.
1012 ft.
Port Bowen
30 Miles
Sea Level
Swain Reef
Sinnmarez Reef
7.
1000 ft.
Broad Sound
Pine
Barrier Reef
30 Miles
Sea Level
Marion Reef
Soundings in fathoms.
B. Meisel lith.

B. Meisel lith.

2243 ft.
14.
Swinger Reef
Marx Reef
Reef
5 Miles
Abt 10 m. to Cape S. Bedford 12 18 fms
Sea Level
Lark Passage
1187 ft.
Lizard Island
17.
5 Miles
Cormorant Pass
Sea Level
13.
Hope Island Flats
5 Miles
Cairns Reef
Sea Level
Turtle Reef
5 Miles
Reef strikes the 20 fm outermost channel
15.
275 ft.
Wooded Isle
Three Isles
5 Miles.
Ef(f) Reef
Marx Reef
Reef
Outer Barrier (linear) to S of Lark Passage
Soundings in fathoms.
16.
1200 ft.
Lookout Pt.
Em(m) Reef
Eagle Reef
448 ft.
Saddle Id
748 ft.
Lizard Id
Reef
Sea Level
Outer Barrier Reef 8 m South Cooks Pass

Soundings in fathoms.

M. A. PHOTO.   ARTOTYPE E. BIERSTADT. N. Y.

NORTHWESTERN POINT, MIDDLE ISLAND.

WOODWORTH, PHOTO.

ARTOTYPE E. BIERSTADT. N. Y.

REEF-FLAT OFF MIDDLE ISLAND.

WOODWORTH. PHOTO

E. BIERSTADT, ARTOTYPE N. Y.

REEF FLAT. MIDDLE ISLAND.

CORAL CONGLOMERATE, MIDDLE ISLAND.

WOODWORTH, PHOTO. ARTOTYPE E. BIERSTADT. N. Y.

A REEF SEEN FROM THE EASTWARD.

M. A. PHOTO.

ARTOTYPE E. BIERSTADT. N. Y.

REEF FLAT, HOPE ISLAND.

W. McM. Woodworth Photo

THREE ISLES, NORTHERN EXTREMITY.

ARTOTYPE, E. BIERSTADT, N. Y.

BEACH EAST SIDE THREE ISLES.

M. A. PHOTO.

ARTOTYPE. E. BIERSTADT. N. Y.

NEGRO HEADS THREE ISLES.

W. MC'M. WOODWORTH, PHOTO.

ARTOTYPE E. BIERSTADT. N. Y.

ELEVATED REEF, THREE ISLES LAGOON.

WOODWORTH. PHOTO

E. BIERSTADT, ARTOTYPE N. Y.

THREE ISLES LAGOON.

ARTOTYPE, E. BIERSTADT. N. Y.

NORTHERN EXTREMITY OF BRAMBLE REEF.

WOODWORTH, PHOTO   ARTOTYPE, E. BIERSTADT, N. Y.

WESTERN EDGE OF CAIRNS REEF.

WOODWORTH PHOTO

E. BIERSTADT, ARTOTYPE N. Y.

WESTERN EDGE OF CAIRNS REEF.

ARTOTYPE E. BIERSTADT. N. Y.

SOUTHWESTERN EXTREMITY OF CAIRNS REEF.

WOODWORTH PHOTO

E. BIERSTADT, ARTOTYPE N. Y.

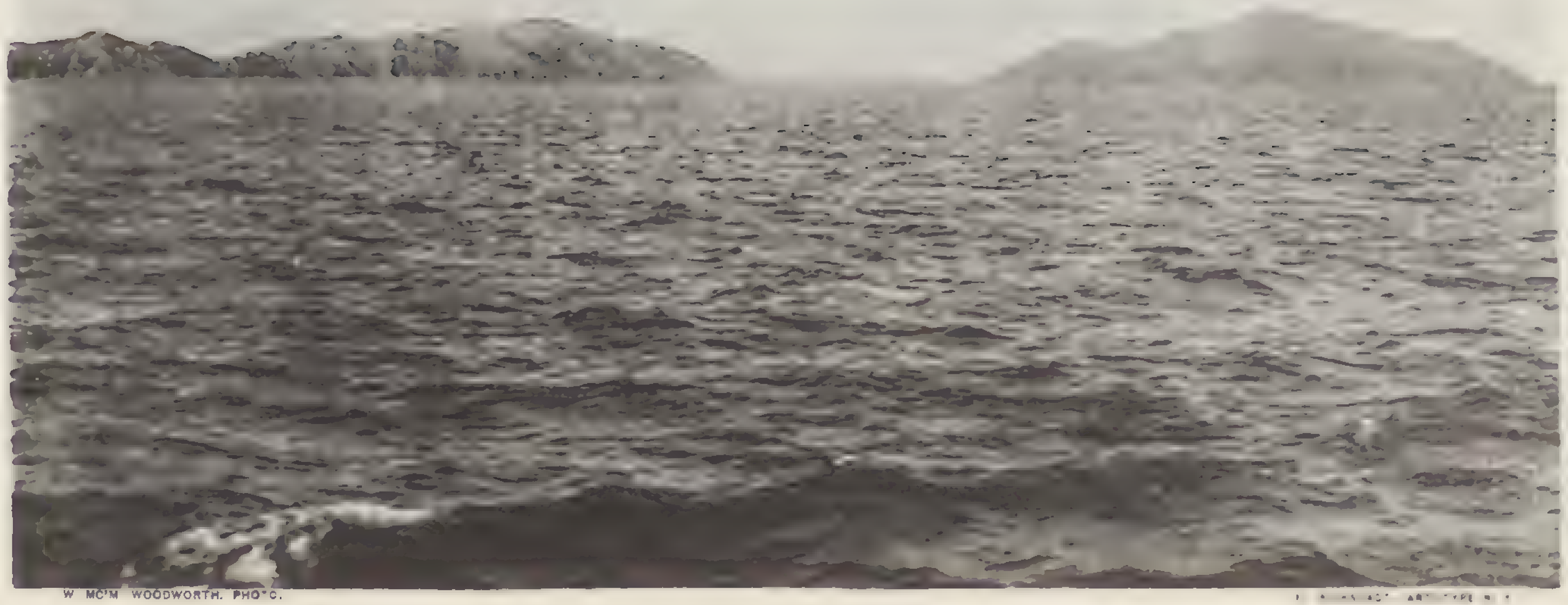
EASTERN SHORE EAGLE REEF ISLAND.

WOODWORTH, PHOTO. ARTOTYPE E. BIERSTADT, N. Y.

WESTERN SHORE EAGLE REEF ISLAND

WOODWORTH, PHOTO. ARTOTYPE E. BIERSTADT. N. Y.

LANGFORD ISLAND.



W. MC'M. WOODWORTH, PHOTO.

ORPHEUS AND NORTH PALM ISLANDS.

S. W. EXTREMITY OF FITZROY ISLAND.

ARTOTYPE E. BIERSTADT, N. Y

SOUTH WEST END OF LIZARD ISLAND.

ARTOTYPE, E. BIERSTADT. N. Y.

NORTH EAST END OF LIZARD ISLAND.

153°20'
North West Channel
Bribie Island
Shimish Pt
North Banks
Spitfire Bank
Howe or North Channel
Flinders Reef
C. Moreton
Pearl Channel
Moreton Island
Moreton Bay
South or Rous Chan
Mud I.
St Helena I.
Hope Banks
Pt Lookout
Peel I.
Stradbroke Island
Innes I.
27°
20'
40'

BREAK SEA SPIT
Sandy Cap
280
326
HERVEY BAY
280
North Gardner Bank
Platypus Bay
320
Indian Head
25°
Gardner Bk
560
BURRUM RIVER
250
710
GREAT SANDY
or
FRASER
ISLAND
530
320
220
684
800
MARY RIVER
400
30
750
GREAT SANDY STRAIT
690
North Sp
292
Outer Bk
South Bk
WIDE BAY
Double Island Pt
26°
153°

150°
Pine Peak I
Broad Sound
High Peak I
Cheviot
North Channel
TOWNSHEND I
SHOALWATER BAY
Normanby Range
Peninsula Range
Clinton
C Manifold

Armit Is
(494)
Hayman I.
MOLLE CHAN
HOOK I.
WHITSUNDAY PASSAGE
Molle I.
WHITSUNDAY I.
Long I.
Hamilton I.
Haslewood I.
Lindeman I.
(712)
C. Conway
Repulse Is
Shaw I.
(1324)
Thomas I.
Anchor Is
Goldsmith I.
CUMBERLAND
ISLANDS
HILLSBOROUGH CHANNEL
Carlise I.
(1277)
Wigton I.
(418)
BLACKWOOD SHOALS
Keswick I.
St Bees I.
(1240)
Scawfell I.
(1305)
Pioneer R.

Low Isles
Port Douglas
Batt Reef
TRINITY OPENING
Oyster Reef
Green I.
Arlington Reef
GRAFTON PAS
Cairns
C. Grafton
2710
Fitzroy I.
860
1016
Sudbury Reef
FLORA PASS
Channel Rf
Cooper Pt
140

Cooktown

64
275
340
893
182
823
750
Pasco Reef
Strickland Rf
Mackay Reefs
Harrier Reef
Marx Reef
Swinger Reef
Bedford
45°20
49

14°40
1179
LIZARD

B. Meisel lith.

Bulletin of the Museum of Comparative Zoölogy

AT HARVARD COLLEGE.

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(GEOLOGICAL SERIES, VOL. III.)

THE GEOLOGICAL HISTORY OF THE ISTHMUS OF PANAMA AND PORTIONS OF COSTA RICA.

BASED UPON A RECONNOISSANCE MADE FOR ALEXANDER AGASSIZ.

BY ROBERT T. HILL.

WITH SPECIAL DETERMINATIONS BY

WILLIAM H. DALL, R M. BAGG, T. W. VAUGHAN, J. E. WOLFF, H. W. TURNER, AND AHE SJÖGREN.

WITH NINETEEN PLATES.

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INTRODUCTION.

The problem of an interoceanic passage, which has attracted commercial exploration to the Isthmus of Panama since the date of its discovery, is accompanied by no greater fascination than that which has attended the purely scientific question of the geologic origin of this narrow bond of union between the North and South American continents.

The geological history of the Isthmus has been a subject of speculation. Zoölogists and paleontologists have written upon the forms of life from the opposing shores, and by comparison have made many able and astute conclusions. The Polyps, Echinoderms, Mollusks, Crustacean

Fishes, and the land fauna have been analyzed to ascertain what light their differentiation would throw upon the period of time when the two oceans were united through the Isthmian passage, but little study has hitherto been actually made of the rocks and their arrangement, of the physiographic features, and of the actual testimony of the geology of the region.

On the 10th of January, 1895, I sailed from New York for Colon on board the steamer "Finance." The third day out we sighted the Bahamas.

Early on the morning of the fourth day we passed close to the elevated wave-cut cliffs and terraces of the east point of Cuba. Beyond Cape Maysi we enter the waters of the Caribbean Sea. Soon we pass the tall mountainous promontories of the west end of the island of Hayti, first Mole St. Nicholas, and a little later the southwest peninsula. These two promontories, the Sierra Maestra range of the Santiago coast of Cuba, and the distant peaks of the Blue Mountains of Jamaica, are composed of distorted sedimentary rocks, and have attained their elevation by excessive folding and crumpling of the strata.

Thus in a single day's sailing we have seen — in the Bahamas, the elevated terraces of Cuba, and the Antillean Mountains — three conspicuous illustrations of methods by which land may be made to rise above the level of the sea. These processes may be epitomized as up-growth, up-lift, and up-folding. The clearness and simplicity with which these processes are revealed by the voyage through the Windward Passage are in marked contrast to the conditions at the Isthmus, where they are complicated by the presence of a fourth kind of land, made by the ejecta of the great volcanic vents of past epochs. Off the southeast ot Hayti and south of Cuba the island of Navassa is passed, and its topography is seen to be a simple illustration of the uplift type of land as shown in the bench and scarp character marking the borders of Cuba. A low bench corresponding to the elevated reef or Soboruco circumscribes the island. Above this rise two cliffs, 100 feet each or more, while the summit is a flat mesa. This island shows that the great epeirogenic movements which have elevated Cuba since Pliocene time extended as far south as Navassa. How wide an area they embraced is an important chapter of Tropical American geology, which will be specially treated in our forthcoming report on the Island of Jamaica.

On the morning of the 17th, our ship comes in sight of the rugged forest clad hills of the Isthmian land and appears to be sailing straight into the Manzanilla headland. No flat surfaces, either beaches, ter-

FIG. 1. The Caribbean Coast of Panama. From United States Hydrographic Chart.

races, or mesa-like summits, are seen; the topography is sharp and jagged, and the coast line abrupt. It was apparent that the study of plains and level surfaces, which are of such aid to the physical geologist, were to be of secondary import in this land. With the exception of the cocoanut palms along the shore line, the thick matted vegetation reminded one of the green hills of New England.

Our steamer closely follows the shore, giving us a good view of Puerto Bello Bay (see Fig. 1) and the village of Punta Gordo. The coast line is straight until the indentations of Las Minas and Nava Bay are reached.

The thousands of steep slopes and drainage valleys of the adjacent land, together with the enormous rainfall (over 150 inches a year), all attest that great erosion is in progress, and that the streams are carrying tons of sediment to the ocean. Yet in passing this coast the absence of deltas or other visible evidence of the accumulation of great sediments from the adjacent land at once strikes the beholder.

Soon we enter the quadrangular Nava Bay, which is an inlet into the coast line, squarely pointed at the sea by Toro and Manzanilla Points, the latter being the northeast corner of the small island upon which Colon is situated.

Upon my arrival at the Isthmus I was cordially received and afforded unusual facilities by the officers of the Panama Railway Company for studying the geology of the section along their line and that of the canal. Had it not been for the untiring accommodation of these gentlemen, the work I accomplished would have required many months of hard labor.

To Colonel A. L. Rives, Superintendent of the Panama Railroad, I am especially indebted for assistance, as well as to all the many employees, especially Mr. G. A. Cunningham, Roadmaster and Civil Engineer of the line. My thanks are also due

to Mr. Josiah Pearcey, U. S. Consul, and Colonel Richard Wintersmith, for their repeated favors and hospitality. I am also indebted to Mr. Shaffer, of the Railway Company, who secured for me transportation and boatmen for paddling down the Chagres and the completed portion of the canal.

After completing the section across the Isthmus I took the steamer from Panama for Punta Arenas, Costa Rica. From the latter point I made a section due east across that country to the Atlantic seaboard at Limon. On this trip I was accompanied from San José to Port Limon by Mr. Abe Sjögren, whose valuable service is repeatedly mentioned in the following pages.

The large collections made by me upon the trip were kindly shipped free of charge to New York upon the Colombian line of steamers by Colonel Rives. In order to secure every possible light upon the collections, I have received the aid of the following specialists, who have kindly assisted me in making determinations.

To Professor G. Brown Goode and Mr. W. J. McGee of the Smithsonian I am specially indebted for the use of the photographs in the illustration of this report. Through their courtesy I was intrusted with a fund for the purchase of objects of interest, and among those secured was a superb collection of photographs of Isthmian and Costa Rican scenery.

Thanks are also due to the Director of the U. S. Geological Survey for the facilities placed at my disposal in preparing this report.

The age of the fossiliferous beds and the determinations of the igneous rocks are those of Dr. Wm. H. Dall of the U. S. Geological Survey, and Professor J. E. Wolff of Harvard College, respectively. Their reports upon the collections are printed as Appendices.

Thanks are also due to Mr. R. M. Bagg, of Johns Hopkins University, to whom were sent the Foraminifera; to Professor F. H. Knowlton, for his determination of fossil plants; to Mr. T. W. Stanton, who has assisted me in the study of the Cretaceous rocks from Costa Rica and in the comparative studies of the Cretaceous faunas relative to the Isthmian problem; to Mr. H. W. Turner, for microscopic studies of the fine earths; to Messrs. Paul and Ohm, of the Petrographic Laboratory of the U. S. Geological Survey, for making sections of all the rocks; and to Master John R. Hudson, of the U. S. Geological Survey, for his assistance in preparing maps and diagrams, as well as to Mr. Frank Burns, for cataloguing and numbering the collections.

The reader should distinctly understand that this report should be considered only in the light of a reconnoissance. An exhaustive study

of the region would require not only the labor of years, but a long residence. The exploration of the Isthmus is as yet very incomplete, and much has been made hastily in order to escape malarial influences; besides, the Isthmus lying between Colon and the Atrato is inhabited by inhospitable Indians, who do not permit the invasion of their country. So that the most elementary features of large areas are still unknown.

I shall endeavor, however, to give a complete geological section across the Isthmus from ocean to ocean, along the line of the Panama Railroad and Canal route, together with such other observations as may have come under my notice. After having presented this section across the narrowest portion of our hemisphere, I shall by way of contrast present a section across the Republic of Costa Rica to the northward, showing a type of the Central American volcanic region.

PART I.

The Geographic Position of the Isthmian Region.

The Humboldtian geography has taught that the two American continents are practically dominated by a continuous Cordilleran system, running like a backbone through South, Central, and North America, connecting the whole western border of the hemisphere into one great mountain system.

The Andean Cordilleran trend, which dominates the western coast of South America, after crossing to the north of the Equator, trifurcates, bends slightly eastward, and abruptly terminates in Northern Colombia. Only one doubtful spur of the Andes touches the coast of the American Mediterranean, and this is the Sierra del Marta, lying between the Gulf of Maracaibo and the River Magdalena. The northern end of the Andean system lies entirely west of the Isthmian region, and is separated from it by the Rio Atrato, and has no genetic connection with that of the north coast of South America, much less with the mountains of Central America, or the great Rocky Mountain region of Mexico and the United States. In fact, the deeply eroded drainage valley of this stream nearly severs the Isthmian region and the Pacific coast of the Republic of Colombia from the South American continent.

Many geographers, especially Felix and Lenk,[1] have shown that the

[1] Ueber die tektonischen Verhältnisse der Republik Mexiko, von Johannes Felix und Hans Lenk. Berlin, 1892. Zeitschrift d. Deutsch. geolog. Gesellschaft, Jahrgang 1892.

main Cordilleran system of Mexico, which is the southern continuation of the Rocky Mountain region of the United States, abruptly terminates with the great scarp or "abfall" of the so called Plateau a little south of the capital of the Republic, and that these mountains have no orographic features in common with those of the Central American region lying to the south thereof.

The trend of the two great North and South American Cordilleras, the Rocky Mountain and the Andean systems, if protracted from their termini in Colombia and Southern Mexico respectively, would not connect through Central America, but would pass each other in parallel lines many hundred miles apart. The protracted Andes would pass through Jamaica and Eastern Cuba, and continue east of the longitude of the whole Appalachian system in the direction of Nova Scotia. A similar southward continuation of the North American Cordilleras would carry them into the waters of the Pacific, crossing the Equator far west of Central America and the South American continent.

Between the widely separated termini of the main North and South American Cordilleras, as above defined, and extending directly across their trend at right angles to them, lies another great orogenic system of folding to which the term Antillean may be applied, and which has been of the utmost importance in giving to the Caribbean region its configuration. It belongs to a system composed of corrugations having an east and west trend, which has never been appreciated by the geologist or geographer owing to the overwhelming proportions of the adjacent volcanic mountains. The corrugations extend along the Venezuelan and Colombian coast of South America, north of the Orinoco, the Isthmus of Panama, Costa Rica, and the eastern parts of Nicaragua, Guatemala, Honduras, Yucatan, Chiapas and Southern Oaxaca, and through the Great Antilles. The mountains trending east and west are made up of granites, eruptives, and folded sedimentary rocks of Paleozoic, Mesozoic, and Czenozoic age in Guatemala and Southern Mexico;[1] of Mesozoic and Czenozoic age in the Antilles, Costa Rica, Venezuela, and Colombia, and of Czenozoic age in Panama.

The two elongated submarine ridges stretching across the Caribbean from the Antilles to the Central American coast, between the Sierra Maestra range of Cuba and the Gulf of Honduras, and from Jamaica to Cape Gracias á Dios respectively, separated by the deep submarine valley known as "Bartlett Deep," have a suggestive and remarkable resemblance to these east and west corrugations of the land.

[1] See further details in later pages of this report.

It will be seen that the Caribbean Sea is almost entirely surrounded on all sides except the east by mountains trending east and west, and by submarine ridges of the Antillean type. The Windward Islands, marking the eastern inlet of the sea, are largely old volcanic heaps.

A distinct class of mountains independent of great lines of folding of the earth crust are the volcanoes. These have grown by extrusion and accumulation. Sometimes they are parasitic upon the folded mother systems, sometimes independent of them. They belong to the great area of igneous eruptivity which, since at least as early as the beginning of Tertiary time, has marked the whole western half of the North American continent, the Caribbean, and the north and west sides of the Andean region. Although blending into each other, the volcanic ejecta of this great belt may be classified for convenience into two distinct age categories, which we may call the quiescent and the active volcanic groups.

The active volcanic groups occur in four widely separated regions: 1. The Andean group of volcanoes of the Equatorial region of western South America, rising above the corrugated folds of the northern termination of the predominant South American Cordilleras. 2. The chain of some twenty-five great cinder cones which stretch east and west across the south end of the Mexican Plateau, protruding parasitic-like upon the terminus of the North American Cordilleras. 3. The Central American group, with its thirty-one active craters, and growing diagonally across the western ends of the east and west folds of the Caribbean corrugations fringing the Pacific side of Guatemala, San Salvador, and Costa Rica. This is separated from the Mexican group on the north by a large non-volcanic area, the Isthmus of Tehuantepec, and on the south from the Andean volcanoes by the Isthmus of Panama, where no active volcanoes are found. 4. The chain of volcanoes of the Windward Islands, marking the eastern gate of the Caribbean Sea, and standing in a line directly across the eastern termini of the Caribbean Mountains, trending east and west, and parallel to the Central American group similarly situated at their western termini.

The Isthmus of Panama, the Pacific coast of South America west of the Atrato, the north coast of South America, the old volcanic areas of Northern Mexico and the United States, and the Great Antilles, are still other regions in which volcanic activity has long been quiescent.

The North American Cordilleran region, lying north of the Isthmus of Tehuantepec, is one of north and south folded sedimentaries, plus accumulations of volcanic intrusions and ejecta, and dominates a continental area.

The Andean region of the South American continent is one of north and south folded sedimentaries plus accumulations of volcanic intrusions and ejecta, and dominates a continental area.

The Caribbean region, including Central America, the Antilles and the Windward Islands, and most of the Venezuelan and Colombian coast of South America, is one of east and west folded sedimentaries plus accumulations of volcanic intrusions and ejecta; but instead of dominating a continental region, *practically constitutes a mountainous perimeter surrounding the depressed basin of the Caribbean.*

Upon this arrangement of the three systems of mountain folds are chiefly dependent the great physical differences between the lands bordering the Gulf of Mexico and the Caribbean Sea. The former in their geognostic aspects and relations are North American, while the latter are distinctly Central American.

The Gulf of Mexico, with the single exception of its extreme southwestern indentation upon the coast of Mexico, is surrounded by gently tilted plains composed of great sheets of subhorizontal sediment largely deposited by its own waters when they occupied a larger area than at present. The entire Gulf margin of the United States and most of Mexico is of this nature, while the north coasts of Yucatan and portions of Cuba, although modified, are related phenomena.

The Central American region as above outlined, — i. e. that portion of the American hemisphere extending from the southern termination of the Rocky Mountain region to the northern termination of the South American Andes, including the southern border of Mexico, the Republics of Central America, and the Isthmus of Panama proper, — constitutes the western perimeter of the mountainous circle enclosing the Caribbean. As a whole it is called by some writers the American Isthmian region. This greater Isthmian (Central American) region is marked by its narrow elongated outlines relative to the broadening areas of the adjacent continent, and the completely mountainous character of its entire topography. Its conspicuous characters are: —

1. The volcanic plateau lying nearer the Pacific coast, from its commencement in Guatemala to its eastern termination in Costa Rica, which is composed of accumulated material extruded across the western termini of the Antillean trends.

2. The lower but mountainous portions of the Caribbean side, composed of folded mountain axes extending in east and west directions in conformable direction with the Antillean uplifts, accompanied by eruptive extrusions of past geologic time.

The most conspicuous eminences are the grand volcanic peaks of Guatemala, San Salvador, and Costa Rica. These rise to an average height of 10,000 feet in irregular masses, standing nearer the Pacific coast than the Atlantic until reaching the Republic of Costa Rica, when they trend diagonally towards the Caribbean side, again assuming in the southern portion of that Republic a central continental position. These great eminences are built up of accumulations of volcanic débris which have buried and largely concealed a most interesting antecedent geologic structure. This older structure must be interpreted before the complete history of the region can be written.

The western termini of the east and west Antillean trends of the Caribbean half of Central America are buried in Guatemala, Honduras, and Costa Rica by the overlying volcanic masses. They are not so limited on the Pacific side of Panama, however, but continue across it.

Upon entering the State of Panama from the west (Costa Rica), signs of recent volcanic activity cease, and the chain of high Central American summits is succeeded by the more broken and apparently intangible lower Isthmian topography.

The Isthmus of Panama can now be accurately defined as the stretch of land lying east of the southern end of the Central American active volcanic region, commonly called the Costa Rican Volcanic Plateau, and extending to the northern termination of the Andes. Its limit on the east is the Rio Atrato, which flows northward from the Equator along the valley marking the western flank of the Andes, and on the west the southern boundary of Costa Rica, stretching from Burica Point to the island of Veraguas, and extending between the meridians of 79° 15′ and 82°, a distance of 180 miles. The axial trend of the Isthmian region is east and west, or in a direction contrary to the north and south continental trends, and conformable with the Antillean axes.

The outline of the Isthmian region is that of a gentle arc extending in an east and west direction, the northern or Caribbean shore being concave in outline, while that of the Pacific is deeply convex and indented by many bays and estuaries.

It has been the custom of later writers to restrict the use of the term "Isthmus of Panama" to the low pass lying between the cities of Colon (formerly Aspinwall) and Panama; but this usage is improper, for the region is a geographic and political unit, and the name should not be restricted to any particular pass across it.

Topographically, the surface of Panama consists of exceedingly irregularly rounded, low pointed mountains and hills covered by dense forests.

Whether composed of igneous or sedimentary rocks, these all have the uniform topographic aspect above described, and their geologic composition cannot be predicated from their appearance, as is the case in most regions of the earth's surface.[1] These hills are irregularly distributed over the surface, and generally without any arrangement into systematic chains or ridges. This is an important point, for most of the maps of the region represent a culminating continental divide or backbone extending along the length of this narrow strip of land, when in fact the summits extend abruptly to either coast, regardless of any axial arrangement. Even upon the islands of Panama Bay these summits exceed in height the continental drainage divides.

It is difficult to convey an idea of the irregularity of distribution and arrangement of these low mountains and hills. Whatever may have been their original configuration, their present shape, distribution, and relative arrangement are largely the result of the erosion of the intensely developed drainage system, and the marine erosion of the bordering seas.

Out of this chaotic condition there are two exceptional indications of systematic arrangement. The southern termination of the high central divide of the Costa Rican region continues due eastward for a short distance into the province of Panama, giving an east and west trend to the topographic crests of the western end of the Isthmus. Southward of this line, and parallel to it in echelon arrangement, is the Cordillera of San Blas, following the Caribbean coast from Puerto Bello a few miles east of Colon to Caledonia Bay, and separating the drainage of the headwaters of the Bayano and Tuyra systems flowing into the Pacific from the waters of the Caribbean. This range of mountains is far from being central, however, but is a marginal accompaniment of the Atlantic border, and its east and west trend can in no manner be made to harmonize with that of the Andes, for if their respective termini could be projected they would intersect at right angles. The trend of the San Blas system is pre-eminently Antillean, and not Andean.

None of the writers on the Andean system connect the Isthmian summits with it. Karsten, Sievers, Reclus, and others, all agree on the character of the termination of the Andes in a threefold range east of the Rio Atrato. Maack alone of the geologists has connected the Isthmian hills with the Andes.[2] He connects the mountains east of

[1] This fact is no doubt due to the deep under surface decay of the rocks, which here renders the surface of both igneous and sedimentary rocks into a homogeneous mantle of red clay.

[2] Report on Geology and Natural History of the Isthmus of Darien and Panama. Selfridge, Naval Reports, Washington, D. C., 1874, p. 156.

the Atrato and a branch of the Andes which he supposed to exist west of that stream in Colombia, a conclusion contrary to facts. The two instances above mentioned are lineally arranged summits. Instead of constituting a continuous trend, it will be seen that they are really parallel ranges.

With the above exceptions, long continued ridges, table lands, or partially dissected plateaus are conspicuously absent, the whole topography consisting of pointed hills from 200 to 1,500 feet in height, separated, sometimes encircled, by drainage valleys deeply incised and cut down approximately to sea level. Our knowledge of the higher summits and topography beyond the low drainage valleys is very deficient. Exploring parties bent on establishing interoceanic connection have followed the stream valleys from either coast, and explored only the lowest passes separating their headwaters.

While the surface in general is hilly, there are a few exceptional and widely separated small areas of approximately level treeless upland country. On the Pacific side, commencing at the mouth of the Bayano and extending to the Costa Rican boundary, occasionally open savannas or treeless plains appear at an altitude far above that of the swamps and present coast line. Some of these attain great extent, such as the Plains of David in the ancient province of Chiriqui.

In common with the whole Central American region south of Yucatan, the Isthmus of Panama presents no such features as a well defined coastal plain, like that bordering the eastern and southern margin of the United States, and composed of the gently lifted and little deformed marginal marine sediments. Such occasional levels as may be recognized on either coast are the products of the erosion of the greatly distorted sedimentaries and volcanic rocks. There are occasional stretches of beach exposed at low tide, like that at Panama, but their continuity is interrupted by abrupt cliffs and mountains coming precipitously to the sea.

The Caribbean coast is generally marked by jagged and abrupt bluffs, where the sea beats directly against the hills. The indentations are slight and far apart. The same may be said of the Pacific side. It is predominated by the great indentations of the Gulf of Panama, dotted by numerous islands, having the same topography and general aspect as the mainland. The shore line of this Gulf is itself indented by many conspicuous inlets, far exceeding in size those of the Caribbean shore, notably the Gulf of San Miguel, which is properly the mouth of the Tuyra. (See Figure 1.)

The continuity of the rugged coast line is broken at frequent intervals by swamp lands usually adjacent to the outlet of some river. These swamp levels extend far inland and constitute a large area of the entire Isthmian topography.

The country adjacent to the Atrato far southward towards the Equator consists of low swampy ground of this character. This is also true of extensive stretches up the principal tributaries of the Tuyra, the Bayano, and the Chagres. Similar patches of low swampy land are also found at intervals along both coasts.

The drainage of the Isthmian region is somewhat complicated and difficult to describe, and is about equally distributed between the two oceans,[1] but does not part from a continuous structurally defined water shed. This drainage consists of streams of great age, the headwaters of which are so minutely ramified that, in the course of their past existence, they have long since etched over every portion of the original surface. These numerous branching ramifications gather into a few arterial channels, emptying into the sea, usually reaching its level so far inland that they become tidal rivers, oftentimes for a distance nearly half way across the Isthmus, thus constituting what would be called "drowned rivers." Technically, this drainage may be defined as ancient, mature, and autogenous, consisting of deeply incised headwater ramifications, "drowned" in their lower courses towards the sea.

In the eastern (South American) half of the Isthmus the drainage consists of a few principal arterial streams, whose interlocking headwater ramifications radiate out over great circular areas like innumerable branches of a low wide spreading tree, gathering from all directions into wide trunks leading to the sea. The Atrato, rising in the Republic of Colombia about at the second meridian, flows almost due north into the Gulf of Darien for a distance of nearly 600 miles, and has a fall of less than one foot per mile for its entire distance. West of this river the Tuyra drains most of the country as far as Panama Bay, carrying the waters into the Pacific. This stream and its tributaries form a remarkably complex system, the digitated headwater ramifications radiating in all directions, reaching almost to the basin of the Atrato on the east and the Atlantic on the north. This is by far the

[1] The details of the drainage, excepting that of the principal arterial trunks, are but poorly known. This is well exemplified on Wiess's map, where all the headwater ramifications are sketched in a conventional manner except in the area adjacent to the Panama Railway surveys, where the characteristic drainage is well shown.

largest drainage basin of the Isthmus proper. Proceeding westward, the central portion of the Isthmus is drained by the Bayano and its tributaries, which, although smaller than the Tuyra drainage, is very extensive. Like the Tuyra its ramifications extend nearly to the Caribbean seaboard, carrying the waters into the Bay of Panama on the Pacific.

Continuing westward, the drainage of the Chagres next sets in. This is like the Tuyra and Bayano, so far as it consists of numerous radiating tributaries collecting into a single arterial outlet to the sea, but its waters are carried into the Caribbean, while its headwaters nearly extend to the Pacific. West of the Chagres to the Costa Rican boundary the drainage consists of simpler or less complicated streams, rising nearer the central or axial line and flowing into either ocean. Thus it will be seen that the drainage of the larger or eastern half of the Isthmus is complex, and finds its way to the ocean by concentrating into three principal arterial channels, while that to the westward is simple. These eastern streams are all tidal for a great distance inland so that the real distance between the waters of the two oceans is much less than that from shore to shore. For instance, while the actual distance from the Caribbean to the Pacific along the line from Colon to Panama is 47 miles, owing to the backing of the tide waters up the Chagres and the Rio Grande, the actual distance of the true marine base level is only a little over half that amount.

The region as a whole, especially the Caribbean side, is covered by a dense jungle of vegetation consisting of grasses, sedges, wild plantain, and trees characteristic of the lower lands of the whole Caribbean coast, lying below 1,000 feet. The peculiar and beautiful arborescent flora which characterizes the higher slopes of Central America and the northern portion of South America does not appear on the Isthmian region.

The Isthmian region differs from the Andean region to the east, not only by the absence of the tremendous heights of the latter, but by an entirely distinct geological structure and composition. The Andes are composed of sedimentaries of the Cretaceous or earlier periods, distorted into gigantic folds and intruded through by igneous rocks. There are no resemblances in age, composition, or structure to this Andean type of topography in the Isthmian region.

Less easily defined, but as strikingly different, is the distinction between the Isthmian region and the high Costa Rican (Central American) volcanic plateau lying to the west of it. These differences are not en-

tirely of altitude, but also of age and structure. This plateau has a foundation of Cretaceous (and in Guatemala earlier sedimentaries) nowhere as yet positively found in the Panama Isthmus. Upon these, in places, are Tertiary sediments similar to those of the Isthmus. These in turn have been buried beneath the thousands of feet of débris from the volcanoes which here have continued active from the Tertiary period to the present, during which time the Isthmian land has been undergoing a general lowering through erosion.

Topographic Evidence bearing upon the Antiquity of the Isthmian Region.

I have represented two parallel adjacent profiles of the Isthmus. (See Plate IV.) One of these is along the line of the canal and railway which follows the lowest passes of the drainage, and conveys an erroneous impression that the country consists of a simple anticlinal slope separated by a continental divide.

The other (Plate IV. Fig. 2) is run in a straight line across the same section, commencing on the west side of Limon Bay, and passing through the Cerro Ançon at the city of Panama and across the Gulf. This profile shows the topography of the country in its natural aspect and relations. It will be seen that, instead of presenting the two well defined coastal slopes and a single continental divide, the country is one of great irregularity, showing no such features. Its hills, called by courtesy mountains, rise precipitously almost directly from the level of each ocean, and occur completely across the Isthmus into the Gulf of Panama, regardless of a continental comb. The whole topography of the region indicates that it is an area of irregular summits arranged without the presence of a single central ridge. The Culebra summit, so called, instead of being the highest point of the mountainous topography representing a continental backbone divide, is excelled in height by many eminences. At Colon the hills on the west side of Limon Bay of the Atlantic shore are almost as lofty as the Culebra summit, while at Gorgona some of the volcanic hills not over a mile south of the road are over 1,000 feet in height. Other eminences a few miles away from the railroad, eastward toward Puerto Bello and in the region of Chorrera, rise to a height of 1,000 and 1,500 feet. In the light of this profile the Culebra summit, as far as it alludes to the continental divide, is a misnomer and misleading. The pass is nothing more or less than an eroded drainage saddle, which has been and is constantly being lowered by the headwaters of the Obispo and Rio Grande. Even the

drainage parting of the Obispo, which flows into the Caribbean, and of the Rio Grande, which flows into the Pacific, is not the site of a simple axis, but is the remnant of what was once a circular central basin which occupied the central region between the Culebra Pass and Mata Chin. The River Obispo was once a small tributary flowing into the southern end of this. By capture through the headwater extension of a lateral of the Chagres the lake was drained, and the Obispo converted into a ramification of that stream.

The Drainage System is Ancient. — Let us now consider the drainage systems of the Isthmus which have been the chief factor in producing this erosion. As shown by the accompanying map (Plate I.), this drainage is exceedingly complex in its ramifications, the headwaters of all the various streams interlocking through low cols between rugose hill topography and the inherited courses of the stream ways are entirely at variance with coastal directions.

The Chagres may be well taken as a type of these streams. This stream gathers into its trunk innumerable branches, which have a general direction north and south in drainage valleys parallel to the coast. While the character of the valleys in the upper portions of the streams indicate long and continuous erosion, the antiquity of the stream is further shown by the fact that it has been so long cut down to sea level that the tides have drowned its lower portion for a distance of 11 miles inland from the Caribbean. Its fall is only 4 feet per mile for 18 miles southward in the direction of Panama, before it makes a sudden bend eastward at Mata Chin towards Puerto Bello, and where, at a distance of 30 miles from the Caribbean coast its bed is only 70 feet above the level of the Atlantic Ocean. In general, distinct terraces or plains indicative of serious alternations of level are not conspicuous, although some of the playas above may be ancient benches.

The Chagres above tide level is cutting into the ancient geologic substructure, and shows no trace whatever of having followed any ancient marine straits or passages, such as must have existed had the seas united across this region in Pleistocene time, as has been fancied by some. Whatever vicissitudes its lower portion may has suffered in its combats with oceanic level, its headwater tributaries have been long and continuously engaged in the task of degrading an ancient barrier, which has persistently separated the two oceans since the beginning of the present drainage.

The other streams of the Isthmian region lying east of the Chagres to the Andes all exhibit the same characters of drowned out mouths

and actively working headwaters. A careful perusal of the explorations of these rivers shows exactly the same conditions to exist along their courses. They are all ancient watercourses up which the tide extends far inland, while the headwaters are cutting into the mountainous barriers. The Atrato, Tuyra, Bayano, and other streams explored, do not flow in straits formerly uniting the two oceans, as has been so frequently represented. The ever lowering cols separating opposing drainages are cut out by the headwater erosion of the rivers themselves in every instance where I could examine them. This is certainly true of the Culebra saddle, the lowest pass in the whole Isthmian region.

The present drowned condition of the mouths of these streams is of great interest, and attracts attention to their past history. The Chagres of the Caribbean coast, and Rio Grande of the Pacific side, whose headwaters ramify near the Culebra Pass, both reach base level far inland of the oceanic borders. The Chagres may be said to reach the marine base level at Gorgona, no rapids occurring below that point. At Barbacoas, 23 miles from the sea, it is only 40 feet above mean tide. In other words, the Chagres is a falling or cutting stream for only two thirds of its total length, the remaining one third of the distance being practically at marine base level. The Rio Grande of the Pacific side from Paraiso towards its mouth traverses the country for about nine miles. About three eighths of its distance, comprising the headwater portion, is a falling stream, the high tides of the Pacific backing up five eighths of its course. It is but a matter of time when the ultimate headwater erosion of the streams will make the long sought communication between the oceans.

The whole Land Surface has suffered general Lowering through Erosion.—What the ancient original configuration of the Isthmian region may have been is a matter of conjecture. It is no stretch of the imagination to say that the general level has been tremendously lowered by this long continued erosion, and that the former heights far exceeded the present altitude. The Isthmus of to-day, instead of being a new made land, is an old and decaying one, which has been dissolving away for ages under the effect of its tremendous rainfall, and is rapidly approaching base level.

From the first sight of the Puerto Bello Islands across the Isthmus until sailing out into the Pacific beyond the rugged points of Cape Mala, the antiquity of this topography is impressed upon the observer. Old age is indelibly stamped upon every feature, and in the course of my

experience in observing the phenomena I have never seen such an advanced example of a decaying region.

Topography of the Submarine Bench. — In considering the Isthmian topography it is necessary to extend our profile seaward in both directions in order to understand the true contour of the cross section, for on both sides there exists a shallow submarine bench, which must have been a continuation of the land in these directions. The submarine bench of the Caribbean is a gradually sloping plain for many miles northward of Colon until the depth of 500 fathoms is reached, presenting a flattened gradient. Then the profile makes a great plunge from 600 to 1,900 fathoms, presenting a submarine escarpment which, although of great height, is not so abrupt as that of the Pacific.

On the Pacific side the waters of Panama Bay are so shallow that their average deepening does not exceed one fathom per mile, until the 100 fathom line is reached, nearly 100 miles south of Panama city. This line will almost connect Cocalita Point and Cape Mala, the two points which mark the entrance to the Gulf. Here, however, almost coincident with the abrupt Pacific coasts, there is a gigantic submarine escarpment plunging off into the Pacific to the depth of 1,700 fathoms or more. These features we have added to the profile of the land on Plate IV. Figure 2.

The submarine topography of Panama Bay is also of deepest interest in interpreting the history of the former magnitude and decay of the land. Not only do the numerous islands stand as monuments to its decay, but the floor of the bay itself reveals a remarkable surface. I have carefully plotted upon the map, as shown in Plate IV., the submarine contours of Panama Bay. The results clearly show the presence of a topography remarkably similar to that of the land, including several deep arterial channels which may have been submerged river valleys. This submarine topography may represent the continuation of the larger rivers many miles out into the region now covered by the Pacific waters, and strongly suggests that the ramifying systems of drainage now visible are but remnants of the headwater portion of what were once far more extensive streams.

There are two great factors in the destruction of the land of the Isthmian region: 1st, the excessive rainfall; and, 2d, the marine erosion of the waters of the Caribbean and Pacific.

The rainfall of the Isthmian region, with the accompanying erosion, is excessive, exceeding any other upon the western hemisphere. For the year 1894, the one preceding my visit, according to the measurements

kept by Mr. Schaffer of the Panama Railway Company, the rainfall was 154 inches. The atmosphere is nearly always saturated with mist, except in the dry season, during the months of January, February, and March. During these months the rainfall is much greater than the mean annual of the United States. It is but natural that such enormous discharges of rainfall acting through long centuries should produce great erosion, and as a result the entire face of the country has been etched by numerous streams, which, although short, are of great volume. The discharge of the Chagres River, the drainage area of which does not exceed 1,000 square miles, varies from 350 to 70,000 cubic feet per second.

Still further evidence of the fact that the present Isthmus is but a remnantal and decaying land is the actual destruction now taking place through marine erosion, which can be seen in operation along the coasts.

The effect of marine erosion npon the coast of the Caribbean is very marked. While the tide does not exceed three feet in ebb and flow, it is accompanied by a very choppy and persistent surf, (no doubt greatly due to the strong trade winds,) which is constantly attacking and carrying away the unconsolidated beds of the coast formations. Notable instances of this action taking place are found in Limon and Manzanilla Bays, where I could see evidence that great areas of the swamp land had but recently been destroyed, are specifically cited on a succeeding page. This effect is also shown in the tidal streams, the alternations of ebb and flow resulting in the undermining and corrasion of the unconsolidated banks.

Perhaps the best illustration of the tremendous effect of this marine erosion on the Caribbean side can be seen upon the hydrographic charts of the Chiriqui Lagoon. Here what was once a coastal plain between Boco del Drago and Valiente Peninsula has been cut into numerous islands.

Were I indulging in hypothetical geology it would be easy to reconstruct a portion of the ancient Caribbean land which has been destroyed by the action of the marine erosion, but it is not my province to enter into such speculations at the present time. It is sufficient to say that it is possible that a vast area of the former coast of the Caribbean coastal land, as it existed in late Tertiary time of the Isthmian region, has been planed away by this agency, now seen to be so actively in operation.

Marine Erosion of the Pacific Coast. — The great difference between the character of the tides upon the Atlantic and Caribbean shores is

well known. While the ebb and flow is only about 27 inches at Colon, the greatest rise and fall at Panama is 21 feet. The impact of this great wave as it beats against the Pacific coast creates a powerful erosive force. The undertow and flow of the tide has also great effect in removing and distributing coastal débris.[1] All of the islands as well as most of the mainland of the Pacific side exhibit, just above low tide level, vertical or concave cliffs corresponding in height to the difference between extreme high and low tides which are being constantly undermined by the tidal action. This tidal cliff is a striking feature of all the sketches in this paper of the Pacific coast and islands in the Bay of Panama. No one glancing at the latter and comparing them with the mainland topography will doubt that they are being slowly but surely destroyed by marine erosion, and that this erosion severed them from the mainland of which they were undoubtedly once a part. And it would require no stretch of the imagination to conceive that the great Gulf of Panama itself may have been cut out in this manner by the progressive indentation of the Pacific Ocean. (See Plate III.)

PART II.

Geology of the Continental Section, Colon to Panama.

The Caribbean Coast.

From the Puerto Bello headlands to Colon, the coastal topography consists of rugged pointed hills rising close from the sea, varying in height, but not exceeding 700 feet. These are separated by deep U-shaped valleys cut down to the level of the sea and extending far inland. Occasionally small beaches or even outlying islets give variety to the rugged coast. Over the hills and valleys spreads the great veil of tropical vegetation concealing all the minor details of the immediate surface.

Colon Harbor. — The quadrangular Nava Bay, which is a square cut inlet into the coast line, is terminated at the sea by the Toro and Manzanilla points, the latter being the northeast corner of the small island upon which Colon is situated. This oblong harbor has no important stream entering it. As one watches the constant force with which the

[1] The jetties constructed recently at Galveston, Texas, have so changed the direction and action of the surf that the beach of Galveston Island is being rapidly washed away. This action is taking place from marine currents, entirely away from the influence of any streams or currents from the land.

choppy waves of the Caribbean are driven into and against it by the trade winds, he cannot but conclude that it owes much of its outline to marine erosion.

Manzanilla Island. — The island upon which Colon is built is now a small square piece of land, which originally, before modified by man, hardly projected above the water as a fringing coral reef.[1] Two thirds of its present area is still a mangrove swamp lying between the sea front and the mainland back of it. Much of the present *terra firma* has been artificially constructed by filling from the work of the railway and canal. The low beach on the Caribbean side is a dead coral reef, exposed between tides, and upon which the surf sweeps débris of shells, coral, tropical sea beans, and other flotsam. At no other point on the island than this beach is there an exposure of consolidated rock.

The island was undoubtedly once a shallow swamp continuous with the mainland, and limited on the seaward edge by the coral reef constituting a narrow neck of land between Nava and Manzanilla Bays. It is now separated from the mainland by a small short strait known as Fox River, only a few yards in width, which has been clearly cut out by wave erosion, destroying the neck which once connected Manzanilla island to the mainland.

Manzanilla Bay. — This is a small bight similar in outline to the larger Nava Bay, but lying to the eastward of the island. Both Nava and Manzanilla Bays show the same type of structure. Where erosion is taking place the surf is muddy and unpropitious for coral growth, but as the surf line extends farther and farther inward the clear marine water line also follows it. Hence the living coral reefs which originally grew on the outer points of the harbors have followed the clear waters along the interior margins of the points of the bays.

The Isthmian Swamps. — From the steamer's deck, occasionally wide flats covered with dense vegetation of plantain, sedges, and grass can be seen skirting the ocean's margin, or extending inland up the flat valleys between the high hills. Limon Bay is largely backed by swamps of this character. With few exceptions the Panama Railway and much of the canal follow these swamps for many miles into the interior. Now and

1 The material of these reefs has been studied and published in several papers by Prof. A. E. Verrill. In Proceedings of the Essex Institute (p. 323, April, 1866), he states that these reefs at Colon (at that time called Aspinwall) "have essentially the same features as those of Florida and the West Indies, . . . but at Panama none of these forms occur, nor even any of the genera or families to which they belong, with the exception of Porites." See also American Naturalist, Vol. III. p. 500, 1869.

then the foot of a range of hills will be skirted, but the swamps continue on as far inland as Bujio.

On the south sides of both Nava and Manzanilla Bays, for instance, the surfaces of these swamps stand about five feet above sea level, and the high swash of the waves is constantly undermining and destroying their substructure, here composed of a brownish dirty colored sand, which under the microscope shows about an equal part of fine grains of quartz (some of which are rounded, others quite jagged and angular) and small rounded grains of igneous rock, all of which are accompanied by numerous marine shells so recent in appearance that the nacreous tints are in many cases preserved. Inland, except along the line of the canal, it was impossible to ascertain the substructure of the swamp level.

There is not sufficient free quartz in the structure of the adjacent land to have furnished the quartz sands in the swamp formation, and from its resemblance to the beach sands of to-day and arrangement in stratified bands, there is little doubt that the substructure of these swamps are not entirely alluvial accumulations, as might at first be suspected, but contain the beach sands of a littoral marine formation which has been elevated since Pleistocene time above the sea. These sands not only border the immediate shore of the bays, but they indent the interior between and behind the first line of hills composed of older Tertiary sediments, around which they are deposited unconformably nearly as far inland as Gatun.

The only light obtainable upon the thickness of the swamp deposit is along the line of the canal dredging where it crosses the swamp north of the Mindi Hills. Here from the bottom of the canal, 28 feet below sea level, the same sediments and shells similar to those seen at the sea margin have been dredged, and now thrown up in the terreplains which border the excavation along this portion of its course. The same character of sedimentation was also seen up the deviation cut, two miles east of the mouth of the canal. In fact this formation has the same aspect a hundred miles west on the Costa Rican coast at Port Limon. I do not assert, however, that all the interior swamps are underlain by this marine formation, for some of them are at a higher level, and there is no way of ascertaining their geologic composition. The important fact is established, however, that bordering and indenting the coast of the Isthmus on the north side is a Pleistocene, or even Post-Pleistocene formation, which represents a former but comparatively recent inland extension of the sea, the sediments of which have been converted into land by a slight but comparatively recent elevation. The new land

made by this elevation once extended over at least what is now Manzanilla Bay and Limon Bay, and probably out seaward some distance. Hence it is equally certain that since these late sediments were thus elevated into land the former seaward extension of the coast has been partially destroyed and its area diminished by the destructive surf erosion.

That the Isthmian region was much narrower than now when these swamps deposits were below sea level is very evident, especially when we consider that similar phenomena occur on the Pacific side for at least four miles inland from the present margin of Panama Bay. The waters of the two oceans now forty-five miles apart, were then fifteen miles nearer together. Let not those who believe that the two oceans were recently united across the Isthmus interpret this former restriction of the Isthmian land as demonstrative of their theory, for it can be shown that when these swamp levels were submerged the two oceans were still separated by a land barrier of even greater height than that of to-day.

Subsection 1. — Colon to Bujio.

Leaving the depot at Colon the railway first passes the swampy land of the lower end of the island, and then crosses the narrow strait known as Fox River, which connects Limon and Manzanilla Bays.

The Monkey Hill Base Levelled Terrace. — Beyond this swamp a low line of hills is met. These are lobed and cut into many individual members, but the eye recognizes readily that their summits, less than a hundred feet in height, are the remnants of a once continuous bench or level.

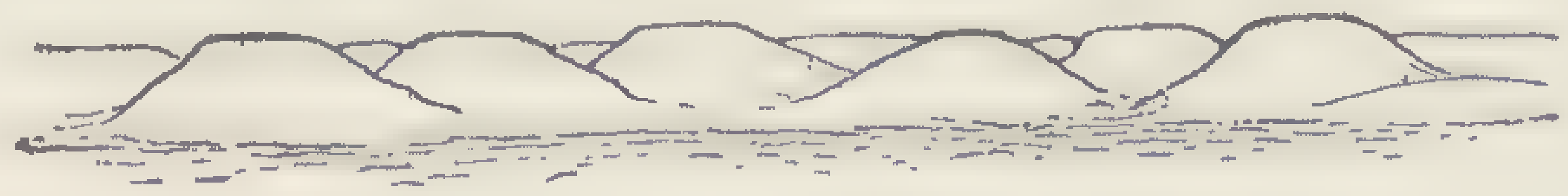

Figure 2. Monkey Hills, near Colon.

The physiography of the Monkey Hills is of great interest. Their uniform summit level, traceable a few miles eastward, parallel to the coast, clearly represents an ancient base levelled surface, probably what was the low coast border when the Mindi swamps were below the waters of the sea. Although this old level has been subjected to later erosion, so much so that it is now dissected into numerous mammillary hills, there can be no misinterpretation of the fact that their summits were once a continuous plain. We may own that this old plain once included Lion and Tiger Hills to the southward, now separated from the Monkey Hills proper by a vast area of swamp. I am inclined to believe, however, that

the former eminences represent the interior upland margin of the old Monkey Hill base level, where the sloping plain was originally about one hundred feet higher than at the station of Monkey Hill.

The Monkey Hill Formation. — Like all the Isthmus these hills are or were once covered by dense vegetation growing from a thick residual soil of red clay. In fact were it not for the artificial cuts of the railway and canal, the true underlying structure would never be seen.

Both the canal and railroad companies have made deep cuttings through the sides of Monkey Hill and reveal the substructure of fossiliferous greensand marl of which it is composed. This marl is dark bluish green in color, sometimes with white calcareous efflorescence, and carries many fossils. The new addition to Colon Island, built by the Canal Company, known as Cristofo Colon, is made of the scrapings of this formation. Collections were made from the cuts at Monkey Hill during the construction of the canal, which, with those made by the writer, as shown in the appended report of Dr. Dall, prove the deposits to be of the age of the Middle or Upper Oligocene Tertiary, and synchronous with deposits in the Antilles, Florida, Trinidad, Curaçoa, and other points, and which throw interesting light upon the history of the whole of the Caribbean region as will be shown later. Most of the railway between Monkey Hill and Gatun is through a low, wide swamp.

Passing only a few yards through the west base of Monkey Hill, the railroad from there to Gatun mostly follows the low swamp level, bordered by occasional hills on the south. Keeping these in view, the remnants of the Monkey Hill level can be seen to back up against the Sierra Quebrancha, a line of higher hills which run parallel to the Caribbean coast back of Gatun Station. These hills are of irregular height, from 300 to 600 feet, and are probably similar to a smaller group cut by the Chagres at Vamos á Vamos.

The structure of the few eminences between Monkey Hill and Gatun could not be ascertained owing to the thick covering of red clay. Sufficient observations in connection with the section to be described along the canal and river were taken to show that these hills were composed of Tertiary sedimentaries.

At Mindi Station (Colon 4.56 miles). The black looking clays of the Tertiary outcrop in the ravine opposite the station, at the end of a new bridge across a ditch. Another outcrop of these beds is shown in the cut through the north end of the hills near Mindi Station, and there can be little doubt that these hills are composed entirely of marine sedimentary material.

We reach the banks of the Chagres at Gatun, $6\frac{60}{100}$ miles from Colon. This river, flowing through banks of unconsolidated terranes, reminds one of the Little Missouri and Ouachita of the wooded region of Arkansas, but it carries a strong volume. Its banks, sometimes 40 feet in height, are of red clay and it has no wide flood plains or conspicuous second bottoms, such as mark the rivers of the Atlantic slope of the United States. In fact, one will find little comfort in studying its valleys in search of benches and terraces such as mark our own coastal streams. Sometimes I thought I could detect to the west of Gatun at Barbacoas and Pena Negra one bench about 40 feet above the bed, but even this is indistinct. The great playa or swamp (Miller and Young's swamp) between San Pablo and Bujio also may represent older levels of the Chagres, corresponding to estuaries at the time the coast swamps were shallow littoral sea bottoms. From one mile below Bujio, to near its mouth, the stream flows through the Monkey Hill Tertiaries. Above that point its tortuous course is mostly through volcanic rock. From Gatun to Bujio the road continues in swamps occasionally running close to the foot of the Quebrancho Hills, and then breaks away across the swamp again. Lion Hill and Tiger Hill, which are parts of this group, are not over 300 feet in height and are all deeply serrated and cut by erosion.

At Bujio Station (Colon miles) the first igneous rocks are encountered in crossing the Isthmus from the Caribbean side, here consisting of volcanic tuffs (Bujio formation) and the marine sedimentaries of the Caribbean side of the Isthmus, containing fossil invertebrates apparently interbedded with them. There is still another sedimentary formation outcropping southward, which may also belong with the Atlantic sedimentaries, which will be discussed later under the head of the Culebra Clays.

Before entering upon a description of the igneous rocks of the central portion of the Isthmus, let us examine a little more thoroughly the sedimentary rocks of the Caribbean side between Colon and Bujio, as seen in the exposures of the cuttings of the Panama Canal from Bujio to Colon.

The Foraminiferal Marls. — About one tenth of a mile northwest of Bujio there is a small mound-shaped hill, spoken of by the French engineers of the canal as a "mamelon." Upon this hill is built the house of the Chef de Section of the canal. Like all other exposures the surface of this hill is residual red clay, but excavations at its base reveal a peculiar calcareo-arenaceous marl abounding in numerous foraminiferal

shells. This marl is not entirely calcareous, however, but is partly composed of volcanic débris. It has been studied by Mr. H. W. Turner of the U. S. Geological Survey, who reports upon it as follows: —

"Foraminifera make up the greater part of the section examined. In addition there are fragments of a slightly greenish augite, and a deep brownish green strongly pleochroic hornblende. A few prisms of feldspar, and very abundant minute clear grains with low gray interference colors presumably also feldspar. The hornblende is brownish (the A ray brown and the C ray deep greenish brown). The augite, hornblende, and feldspar probably all came from volcanic rocks."

At this locality it was impossible to ascertain the stratigraphic relation of this foraminiferal material to the Bujio bluff of igneous material, but from their relative positions it apparently lies unconformably against the latter. Three fourths of a mile below Bujio in the cutting of the canal the same rock crops out, much jointed and so broken that its beds dip as high as 20 per cent in places. This is a more recent and less decomposed exposure of the same foraminiferal beds than at the house of the Chef de Section. One mile below, northwest of Bujio, we reached the Chagres, and in the lower part of its banks, composed of red clay, the foraminiferal marls can again be seen at the water's edge in their unweathered condition.

Crossing the Chagres we came to the plantation of Mr. Shaffer of the Panama Railway Company, who procured canoes to take me down

FIGURE 3. Section on Mr. Shaffer's Farm near Pena Negra, showing Contact of Foraminiferal Marl with Boulder Formation.

25 kilometers of the completed canal between this point and Colon. About 200 yards up the river from Mr. Shaffer's house is a hill known as the Pena Negra. This is of the same type of topography as nearly all the hills of the Isthmus, sharply pointed, with precipitous slopes, covered with dense vegetation, and is apparently in strike with the hills

of igneous material at Bujio. The Chagres has cut a precipitous bluff into the side of this hill, creating a fresh exposure where the relation of the rocks may be studied. This hill is composed of a mass of the peculiar rounded igneous rocks which elsewhere are described more fully. This material continues from the summit of the hill to the water's edge. On the Caribbean side of this hill is a clean contact of the marine sedimentary rocks, resting unconformably upon and against this old transported volcanic material. The basement Tertiary rocks are the same foraminiferal marls traced from the mamelon of the Chef de Section at Bujio, and interstratified with it boulders of the igneous rocks derived from the adjacent beds. This contact, as well as the igneous material contained in the sedimentaries, clearly proves the important point that some of the Tertiary sediments are of later age, and deposited against some of the old igneous material. The character of this contact is given in Figure 3. From their geographic position and inclination I was inclined to believe that these foraminiferal marls were the lowest of the fossiliferous Tertiary sediments of this locality. Dr. Dall, however, is inclined from paleontologic testimony to believe that they belong above the Vamos á Vamos beds next to be described. If his conclusion is correct, the present relation of the disturbed beds would only be explained by a complete overthrow, which I do not think probable.

Section along Line of Panama Canal. — From Pena Negra we paddled down the Chagres and Panama Canal, 22 kilometers, to Colon, securing under better conditions of observation another and parallel section of the country traversed by rail from Colon to Bujio.

Kilometer 22 *to Kilometer* 20. — Our boat follows the Chagres, touching the shores frequently to examine the nature of the banks. The dark green and black marls of the Tertiary are the only rocks met with along the river. From such glimpses of the substructure as could be obtained beneath the red alluvium of the river, it could be seen that these Tertiary sediments had been much disturbed and distorted since their deposition.

Kilometer 20. — *The Vamos á Vamos Beds.* — We have abandoned the old river channel, and are now in the main canal cutting. On the left hand side of the river at Vamos á Vamos rises a vertical bluff some 200 feet in height, which is apparently an outlying hill of the Quebrancho range previously described. The rock composing this bluff is so black in color (greenish black on fracture) that at first glance it seemed to be composed of igneous material as Professor Wolff's report has shown

it largely to be. On closer examination, however, this is found to be of undoubted sedimentary character, being distinctly stratified, and accompanied by great round black calcareous concretions, full of fossil shells. The exposure (Fig. 4) has, in general, a strong dip of over 30 degrees toward the Caribbean coast. These rocks are intensely faulted,

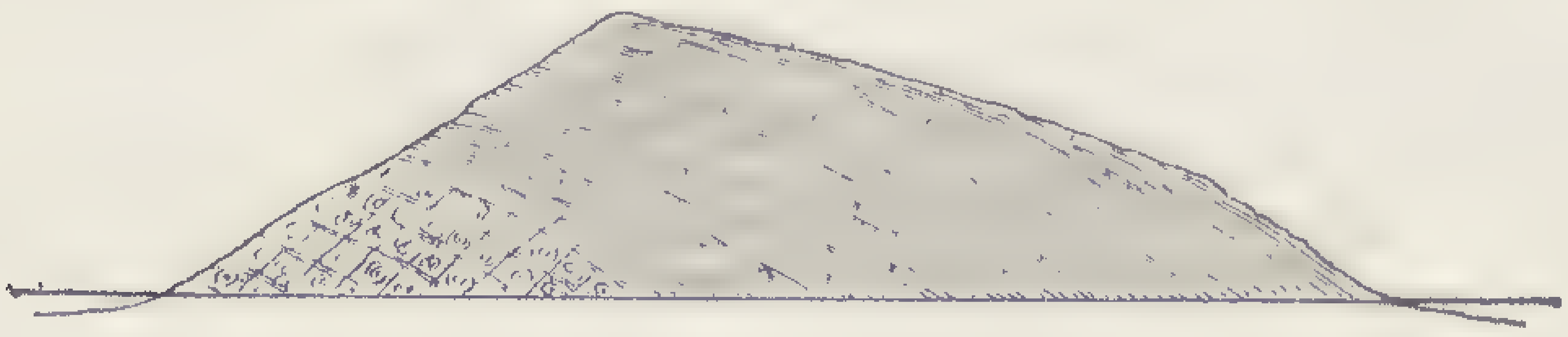

FIGURE 4. Section at Vamos á Vamos.

jointed, and in some places slightly folded. This is one of the most interesting and important localities of the whole Central American region, and will be frequently referred to in this report. The fossils collected from this locality have been examined by Dr. Dall, who definitely refers the age of the deposit to that of the Claiborne epoch of the Eocene Tertiary.

Surrounding the base of this bluff on both sides of the river the banks are mostly alluvial clay, and contain lignite in small pieces. It is evident that most of the region has long since been base-levelled with the exception of this hill, so that it now stands as the remnant of the limb of a former anticline.

Kilometer 20 *to Kilometer* 15. — I was unable to form any conclusion concerning the red clay formations of the banks along this portion of the course. They may be old river alluvium, which has been spread over an eroded surface, or the less indurated residuum of the Tertiary beds.

At Kilometer 15. — Another outcrop of the water's edge of the Vamos á Vamos beds is passed. Here the rocks still have a distinct dip to the northward toward the Caribbean.

Kilometer 13½. — Another low mass of the Vamos á Vamos formation appears on both sides of the canal, covered by the red clay.

Kilometer 12. — Black and blue-black lignitic alluvial clays continue to form the banks.

Kilometer 10½. — *The Mindi Hill Beds.* — Here a deviation of the canal turns off into the river towards Gatun, and the marls in the banks of the river begin to change in character and appearance. The older Vamos beds are succeeded by green sand marls of a finer, more uniform and homogeneous texture and structure, void of lamination. They are evidently a higher subdivision of the same Tertiaries as the Vamos á

Vamos beds, as shown by Dr. Dall's report upon the fossils. About half a mile south of Gatun on the canal is seen a bluff composed entirely of green marls, and containing many large and beautiful fossils. Otherwise than a few little joints and faults, it has almost a horizontal structure, dipping slightly coastward.

Kilometer 9. — The greensand marls continue at the low water line of the river, the upper banks being red clay.

Kilometer 8. — From here on to Colon the canal is mostly cut through the swamps, only one more outcrop of the older hill structure being exposed.

Kilometer 6. — The canal here cuts the eastern base of the Mindi Hills, exposing a bluff over 100 feet in height, which is composed entirely of the Tertiary greensand marls previously noted since leaving Gatun. Topographically the Mindi Hills are evidently a continuation of the Monkey Hill base level, but the strata composing them are older, belonging to the Eocene, while the latter are of the Oligocene age, as shown by Dall.

From Kilometer 5 *to Kilometer* 3. — After passing the cut through Mindi Hill the canal continues through the swamps. The terreplanes thrown up by the dredges are all the fossiliferous sandy material dredged up from the canal, the bottom of the canal extending to 28 feet below sea level, and is the same as the material of the coastal swamps described on page 173, and contains innumerable shells of species not older than the Pleistocene, many of which are still living in the adjacent water.

Kilometer 4½. — Here the canal touches the land, or inner end, of Nava Bay. We stopped to study the swamp formation which here forms the interior border of the bay, and ascertained that it is made up of the same material previously described along the canal and abounding in the same mollusca. The destructive effect of the choppy surf is rapidly destroying the coast at this point.

From kilometer 4½ to the terminus at Colon the canal continues through the swamp formation.

Fox River and Manzanilla Bay. — In order to examine further the formations of the coast I passed through Fox River and into the rear end of Manzanilla Bay, and thence up the artificial cut known as the deviation, entering the back end of the bay. The swamp lands surrounding the outlet of the deviation for about half a kilometer of its distance are composed of the same recent fossiliferous formation as the Mindi swamp and contained similar littoral shells. Inland the deviation passes a vertical cutting of over 50 feet, through the base of the Monkey Hills.

This consists of greensand lithologically similar to that of the Mindi Cut, and also rich in fossils, which according to Dr. Dall's report are similar to those obtained from the cut through the Mindi Hills on the canal. The strata are almost horizontal.

Bujio to the Pacific. — From Bujio, 15.45 miles from Colon, to the Pacific, at Panama, the railway and canal enter and extend through a peculiar hilly region, composed largely but not entirely of igneous rocks, — massive conglomerates and tuffs confusedly mixed with sedimentaries and igneous débris. It is difficult to convey to one who has never seen this region an idea of its topography and geology. It is marked on every side by conical hills with steeply sloping sides and pointed summits (see Fig. 5), not over 500 feet in height immediately along the line of this section, but rising to 1,000 feet or more a few miles away from the railroad. Erosion has long since stripped away all the original surfaces, and the present surfaces are the rocks which formerly constituted the deep substructure of the original topography, whatever that may have been. The canal and railway follow up the valley of the Chagres as far as Mata Chin, from which point they continue up the Rio Obispo, not only to the Culebra Pass, but through it to the south of the summit.

FIGURE 5. Hill near Mamei, showing typical Isthmian Eminence.

The hills of igneous rocks do not differ materially in configuration from those elsewhere seen composed entirely of sedimentary rocks, and it is only in the artificial cuttings of the railway and canal into their bases that some insight into their geologic composition can be determined.

This region as a whole, lying between the high tides of the Chagres on the north and the Rio Grande on the south, may be spoken of as the central region, but it is arbitrarily divided, for geologic discussion at least, into four distinct subsections: —

1. The Barbacoas Subsection. — That portion lying between Bujio Salado and the Station of Baila Monos.

2. The Mata Chin Subsection. — From Baila Monos to Las Cascadas near the upper falls of the Obispo.

3. The Culebra Subsection. — From Cascadas through the Culebra Pass to Paraiso.

4. The Pacific Subsection. — From Paraiso to the Pacific coast at Panama.

The Barbacoas Subsection.

The Bujio Formation. — The igneous tuffs near Bujio station (Colon 15.45 miles) constitute the range of high cerros lying back of the station, and extend across the Chagres River in the direction of Pena Blanca (see hills on background of Plate IX.). The Panama Railway Company has been quarrying the side of this hill for years, and a vertical quarry face, some 40 feet high, affords a good exposure for the study of the material. This is composed of rounded and angular fragments of black massive igneous rock (augite-porphyrite, Wolff) cemented by a matrix of decomposed brownish tuff. At first glance it has the aspect of being the ordinary ejecta of a volcanic vent, but on closer study of its arrangement, and the rounded character of many of the fragments, there seems every reason for believing that it is a conglomerate which has been sorted under water and arranged in banded and cross bedded structure. The stratification planes have a slight dip to the northward, in harmony with the general dip of the overlying fossiliferous sedimentaries.

The Pena Negra hill, to the northward one mile, is in strike with the Bujio hill, but is composed of a much coarser conglomerate, the material assuming the proportion of boulders, two specimens of which were of augite andesite.

At Pena Negra the contact between the foraminiferal marls and the igneous conglomerate was clearly seen. That the foraminiferal marls have been deposited later, and against the Bujio igneous conglomerate, has been shown by Mr. H. W. Turner, who reports that the former contain some of the débris of the latter in its sedimentation, so that the Bujio tuffs and Pena Negra boulders clearly represent volcanic débris of contemporaneous or earlier origin than the fossilferous upper Eocene Tertiary sediments.

The Baila Monos Plain. — From Bujio southward to Baila Monos the road follows a wide basin-shaped plain, sometimes three miles wide, surrounded by low hills of the Bujio type. This is an old alluvial plain of the Chagres, probably representing the lower portion of that river at the period of the swamp level subsidence. Its mean elevation opposite Barbacoas is 60 feet above the Caribbean. The low hills surrounding this ancient valley or planation surface of the Chagres are composed of a peculiar formation which will now be described.

The Barbacoas Formation. — After leaving Bujio the railway runs through a hill skirted plain, slightly rolling, and less swampy in character than those hitherto passed. No outcrops are seen until Frijoles

Station is reached, where the stream of the same name has cut down through the clays to a black rock similar to that of Bujio.

At Tavernilla Station (Colon 21.5 miles) the Canal Company has cut into a small hill apparently composed of red clay. At its base is the first undoubted exposure of a peculiar rock which may be called temporarily the Barbacoas formation.

At Barbacoas (Colon 23 miles) the railway crosses the Chagres upon the bridge resting on a vertical bluff of some 30 feet in height. Rising above the track is a hill some 40 feet or more, making in all an exposure of some 70 feet of the rocks which dip slightly northward towards the Caribbean coast.

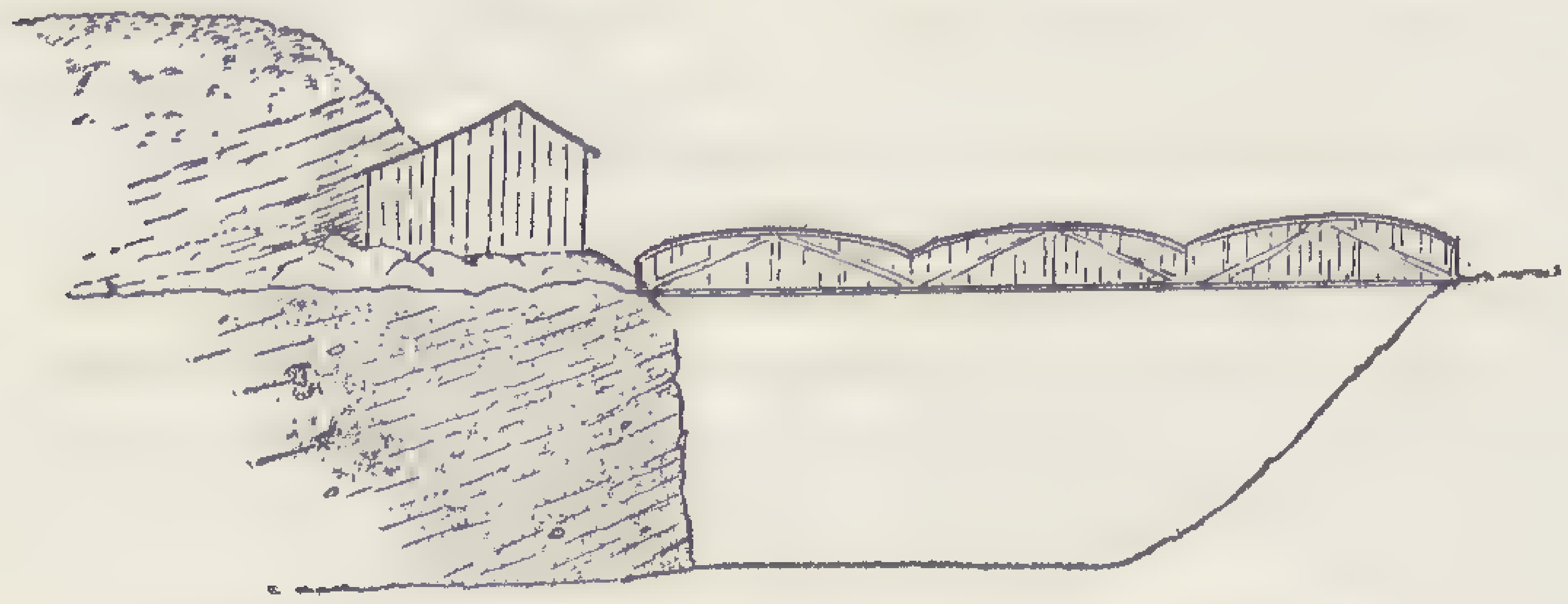

FIGURE 6. Section across Chagres River at Barbacoas.

The first sight of this bluff created the impression of a stratified chalky limestone, but closer examination showed it to consist of a loosely cemented, white earthy rock, composed of firm fine particles, apparently siliceous, but water sorted, and showing distinct lines of lamination, in alternating degrees of fineness and coarseness. Throughout the mass were numerous white specks of a softer material, which seemed to be the small rounded decomposing pebbles of rhyolite. Macroscopically this earth strongly resembled the Radiolarian beds of Cuba, and the volcanic glass deposits of the Great Plains region of the United States.

I was also fortunate in finding the basement relations of the Barbacoas beds at the village of San Pablo, half a mile to the west of Barbacoas. About 100 yards west of the station of San Pablo the white Barbacoas formation grades down into a mass of brownish rock, studded with fragments of decomposed light blue eruptive pieces embedded in it. It has an earthy texture and is easily cut with a hammer. It is of light specific gravity, and apparently a long decomposed conglomerate of volcanic material. This we may call the San Pablo phase of the Barba-

coas formation. This brown material of the San Pablo character also outcrops in the bed of the river across from San Pablo. This formation apparently extends as far south as Mamei.

The Barbacoas rock was composed mostly of jagged fragments of siliceous material which both Prof. Wolff and Mr. Turner pronounce to be rhyolitic pumice. Black specks of basic igneous material are rare or entirely wanting. Upon examination with a high objective I saw some fragments which suggested that, while most of the material may be pumice, there might be siliceous shells of diatoms among it.

Specimens of the peculiar rocks of Barbacoas, Tavernilla, and San Pablo, were submitted to Mr. H. W. Turner, of the U. S. Geological Survey, who writes: —

"The two whitish rocks from the Isthmus of Panama, one from Barbacoas, and the other from San Pablo (No. 37), are both composed almost wholly of volcanic glass, in which are fragmentary feldspars, apparently in part sanidine, but plagioclase is also present. The glass is extremely porous, and is in fact a pumice in structure. It resembles very markedly a true pumice from Lipari, except that there is present a large amount of a brownish decomposition product, whitish and opaque in reflected light. A chemical analysis of the material from Barbacoas was made by Dr. W. F. Hillebrand, and is as follows.

	Barbacoas Glass.	Decomposed Rhyolite. California.
Silica	58.13	51.02
Potassa	1.24	.48
Soda	.64	.22
Lithia	trace	

"The Barbacoas volcanic glass is thus altogether too low in silica and alkali contents to constitute a true pumice, but this may be due in part to decomposition. The analysis of a decomposed rhyolite collected by the writer from the hydraulic washing one mile northwest of Volcano in Amador County, California, and analyzed by Dr. Hillebrand, shows an even greater loss of silica and alkali. The glass groundmass of the California rock, however, is pretty thoroughly decomposed, but the abundant sanidine phenocrysts are little altered. It is therefore not impossible that the Barbacoas glass is a true pumice (that is to say, a porous rhyolitic glass) which is somewhat decomposed.

"No. 35, a white rock composed of rounded whitish particles cemented by similar material, and labelled Barbacoas formation, below red soil at Tavernilla. This is also composed almost entirely of volcanic glass, which is full of gas or steam pores, many of which are drawn out in one direction. The rounded particles seen by the naked eye are minute fragments of pumice that appear to have been somewhat rolled about. These are cemented by porous glass that contains numerous clear, broken, or imperfect crystals, apparently feldspar. There is also some brownish decomposition material present, but on

the whole the glass is much fresher than that of the specimens first described. There is also present in the thin sections examined a ragged prism of greenish brown hornblende with marked cleavage such as is sometimes found in coarse hornblende-andesites, and two blue dichroic grains, which appear to be corundum, and a squarish grain of iron oxide.

"An analysis by Mr. George Steiger of the U. S. Geological Survey shows this glass to be of rhyolitic origin, and as it is of the nature of a sediment it may be termed a pumice-tuff. The preponderance of the soda over the potassa would indicate that the rock is from a soda-rhyolite magma, and it will be of interest to note hereafter if soda-rhyolites exist there.

No. 35. Tavernilla Pumice.

Silica	74.43
Potassa	1.43
Soda	5.61

"It is not safe to say, without much more extended information as to the relation of these rocks in the field, whether or not they are all from the same source, but the two first described, that from Barbacoas and the one labelled 37 (San Pablo) are pretty surely the same. The grains of corundum? in No. 35 may have come from an older schist series."

The conclusions of Professor Wolff, who independently examined these rocks, closely coincide with those of Professor Turner. He says: —

"20, 23, and 36 are the same. They have bothered me considerably, but I have concluded that they are composed of an acid rhyolitic pumice much like that found in beds in some of the Western States. Also 37.

"(20) Isthmus of Panama. Miraflores. Same as 23 and 36.

"(23) Isthmus of Panama. Barbacoas crossing of the Chagres River.

"(36) Barbacoas Formation at Barbacoas, Isthmus of Panama. In the hand specimen a white kaolin-like mass, soft, which in the thin section is entirely without action on polarized light. It may be opal? The rock contains fragments of feldspar and shells, which have been replaced by the silica. The material is clear and iso-tropic in polarized light, contains curious round or elliptical bodies (lapilli). It gives the test for a silicate and fuses rather easily to a clear glass. Seems to be rhyolite pumice.

"(37) San Pablo, Isthmus of Panama. A dirty gray marl-like rock with green spots. Contains sanidine crystals and augite. The feldspar is honeycombed with original glass inclusions. The cement is a greenish isotropic substance with frequent round or oval bodies, which are now replaced by silica. Probably an altered rhyolite pumice. Much like 23 and 36."

The reports of these two authorities clearly coincide in the opinion that this vast formation, which must be somewhere between 500 and 1,000 feet thick, is a rhyolitic pumice and hence of igneous origin.

Stratigraphically it is clearly sedimentary in nature, and water sorted, and must represent the ejecta of some tremendous rhyolitic eruptive epoch, preceding the time of the foraminiferal marls of the late Claiborne Eocene.

The Barbacoas and San Pablo formations are not superficial, but very old, as is shown by their dip in a direction that would carry them beneath all the rocks thus far described, and the fact that the bed of the Chagres is now cutting through them.

Their position indicates that they are far below the conglomerates of the Bujio and Pena Negra hills, which in turn underlie the Claiborne or upper Eocene. The formation between the Barbacoas and Bujio formations is concealed by the jungle, but my impression on the spot was that it might be the Culebra clays to be described. The Barbacoas formation apparently continues as far south as Mamei. In my opinion, based upon other facts to be given later, they were derived from igneous loci existing to the southward, prior to the first recognizable beds of the Eocene period.

The Mata Chin Subsection.

(See Plate V. Fig. 1.)

South of Bailo Monos begins the truly mountainous region of the central Isthmus, and from that point (altitude 63 feet) to Cascadas (altitude 165 feet) the river, followed by railroad and canal, passes through deep V-shaped gorges, void of well defined benches between the high, close set, conical hills. The water gap of the Chagres through this region is a rapid succession of steep bluffs, composed of large spherical boulders of basic igneous rocks, which rest on protruding truncated ends of masses of ancient massive igneous rocks and consolidated tuffs. The hills through which the river cuts in this particular subsection are the eastern periphery of the numerous eminences surrounding the Culebra basin, to be described later on.

The Mata Chin Formation (*"Nigger Head" Bluffs*). — The great bluffs of black basic rounded igneous boulders are called by various names, such as "bomb-shell bluffs," "nigger head" bluffs, etc. Some of the highest hills are composed entirely of these igneous boulders and topographically resemble those entirely made up of massive rock, and are ordinarily indistinguishable from them. The boulders are always thoroughly rounded and apparently rolled.[1]

[1] The term boulder formation if applied to these rocks might create confusion, because throughout Central America and the Isthmian region the term boulder

The face of a great hill composed entirely of these rounded boulders is seen on the west side of the track at Mamei. The first bluff south of Mata Chin is also composed of this rounded material. At Juan Grande the face of the hill shows 110 feet of the formation. Another is found about 100 feet south of Bas Obispo, while the Pena Negra hill previously described at the contact of the foraminiferal marls of the Caribbean section is also composed of the material.

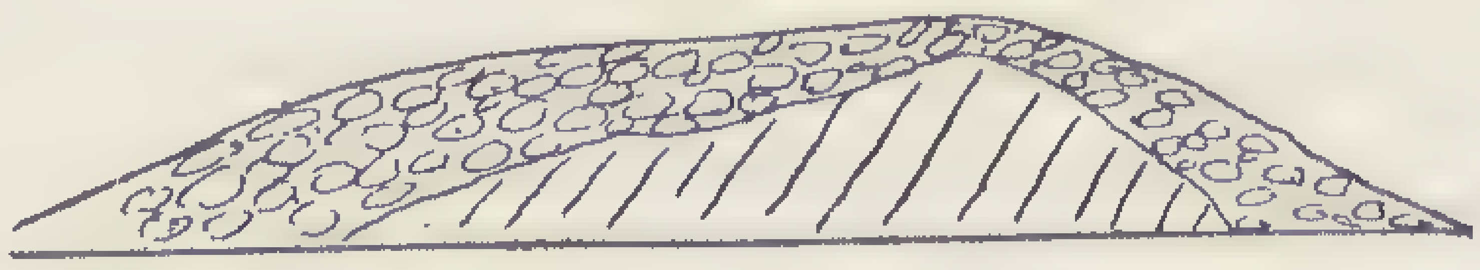

FIGURE 7. Bluff at Mata Chin, showing Superposition of the Boulder Formation upon massive Basic Igneous Rocks.

At first sight of the exposure of these hills I was under an impression that they represented the rounded exfoliated weathering so common in doleritic rocks, but upon close examination I became convinced that they were individual stones which had been rolled and accumulated, and are the débris of the older massive rocks. At several points the boulders were found in unconformable contact with the underlying floor of a basaltic rock, especially in the bluffs at Mata Chin and Bas Obispo. They undoubtedly represent water or gravity rolled detritus of a time when the igneous masses of the interior were much higher than now. From the great thickness of this accumulation, and their occurrence beneath the marine Tertiary rocks in at least one locality, Pena Blanca, together with the fact that at both Juan Grande and Mamei the boulders are overlain by old looking beds of finer and more consolidated material resembling the tuffs and pumices of Barbacoas rocks, I am of the impression that much of this débris is older than the Vamos á Vamos Tertiary sediments of the Caribbean section.

The outcrops of the boulder hills and bluffs, so far as my observation extended, may be said to reach from Bujio to Bas Obispo, entirely on the Caribbean side of the Isthmus. I could find nothing south of Cascadas, at the north end of the Culebra subsection, or on the Pacific slope, corresponding to this great accumulation of igneous débris on the Caribbean side of the Isthmus. Beyond Cascadas to Paraiso the hills

clay has been used for great deposits of igneous material embedded in red clay. In such deposits the boulders are usually angular or little rounded. The hills we are trying to describe, on the other hand, are made up of rounded, much rolled pieces.

are almost entirely composed of the massive igneous rocks or consolidated tuffs.

The disappearance of these boulder hills to the southward, coincident with the point where our section leaves the Chagres, may suggest that they represent accumulations in the ancient valley of that stream. But the absence of intermixed river silt or pebbles of different rocks stands in opposition to such an hypothesis, especially when taken in connection with the fact that these peculiar boulders are not found in any of the present river deposits. I am inclined to think that they represent rolled hillside volcanic débris of contemporaneous age with the great basic igneous eruptions of Cretaceous and Eocene time.

The Massive Igneous Rocks. — Near the 25-mile post from Colon, between Baila Monos and Mamei, beneath a high bluff of the Mata Chin boulders, the first exposure of the massive igneous rocks is encountered in the cuts of the railway and canal, and from thence on to Paraiso they are frequently seen. Specimens were collected from every possible outcrop, the petrographic nature of which has been kindly determined by Professor Wolff. These massives are all ancient, half decomposed dark colored rocks.

They do not now occur as horizontal sheets or lava caps, but project vertically from below as if the remnants of ancient protrusions, the upward continuation of which has long since been destroyed or usually buried by later débris. Owing to the great subaerial decay and dense vegetation it was utterly impossible in this region to trace these rocks to the summits of the hills. Between Mamei and Cascadas they are only exposed in the fresh cuts of the canal and railroad in the base of the innumerable high hills which characterize this region. From Cascadas to the Pacific they outcrop more boldly, being exposed to the summits of the high hills like those of Culebra, Lirio, and Paraiso.

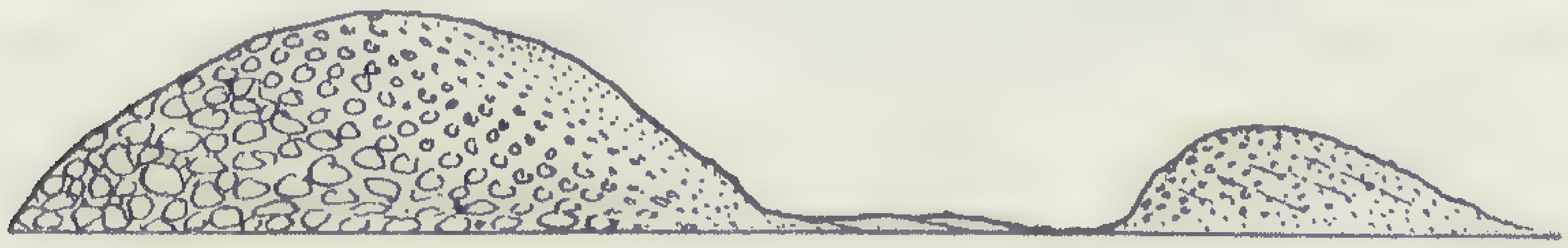

FIGURE 8. Section near Mamei, showing Gradation of Mata Chin Boulders into finer Material.

The accompanying figure of the outcrop at Mamei and the illustration of the canal cutting at San Pablo (Plate X.) show how these rocks are at present exposed. Outcrops of this nature were studied at Mamei, Mata

Chin, Bas Obispo, Haut Obispo, and Las Cascadas, where the Culebra basin begins. The outcrops of basic igneous rocks south of this point of the Pacific are all different in occurrence and in character, and, as I shall show, probably belong to a different period of intrusion.

The massive igneous rocks *in situ* of this subsection (see Plate V. Fig. 1), as above explained, exposed in the deepest cuttings along the lowest levels, and covered north of Bas Obispo by the great accumulations like the Mata Chin boulders, are of the greatest interest in the Isthmian history. At Mamei, in the cuts of the railroad at the base of a high hill in the south edge of that town, is seen the first of the massives encountered in crossing the Isthmus. This is of a basaltic nature, but apparently a tuff. Unfortunately, no specimen from this exact locality was obtained for petrographic study.

At Mata Chin another outcrop of black massive igneous rock is seen beneath a vast bluff of the unconformable Nigger Head (Mata Chin) formation. This rock, according to Professor Wolff's determination, is basalt. From Bas Obispo to Las Cascadas the railway and canal run through a narrow gorge composed almost entirely of all the igneous rocks, both massive and pyroclastic. At Bas Obispo these consist of tuff, containing fragments of basic eruptives and consolidated by a siliceous cement. Less than one tenth of a mile to the southward another mass consists of badly decomposed olivine basalt or melaphyre. Half a mile beyond the composition is a tuff of augite porphyrite. Within a hundred yards to the southward the material is decomposed augite andesite. Entering Las Cascadas one mile to the southward, the material is a reddish silicified tuff with fragments of eruptives, immediately succeeded by reddish trachite. One tenth of a mile beyond, in the Upper Falls of the Obispo River at Las Cascadas, the stream flows over eruptive augite porphyrite.

These numerous exposures are apparently at present one continuous mass of igneous material, but from the diverse mineralogic and physical composition it is very evident that it is neither homogeneous nor synchronous in all its parts, but represents an igneous area in which successive intrusions and eruptions have taken place, in time so long past that the whole — porphyrites, andesites, tuffs, and basalts — have been rotted, decomposed, and sometimes recemented into apparent homogeneity.

In no case does the original igneous material, although some of it was originally surface flows, appear to have formed the present topographic surfaces, but it is all apparently the remnant of very ancient intrusions,

which have been partially destroyed by erosion and covered by later deposits in the whole section. At no point could I find any trace of modern lava flows or erupted material. In all cases they appear to be the intrusive necks of igneous rocks or buried flows.

These rocks constitute the lowest strata exposed in the Mata Chin section.

The Red Clays. — Before leaving this section mention must be made of certain red clays seen along the railway between Juan Grande and Gorgona. These differ from the homogeneous residual clays of the igneous rocks, and the greensand beds of the Caribbean sedimentaries as at Monkey Hill, in that they consist of alternations of distinct laminæ of white and red material. They do not present the sedimental irregularities of river alluvium, and strongly resemble certain phenomena to be further described in the discussion of the Culebra section.

Just south of Mata Chin the line of our section leaves the Chagres River, and takes up the course of the Obispo. The main Chagres makes a great bend at this point, almost a right angle, its headwaters deflecting eastward into the unexplored interior region, while in that portion of its course between Mamei and the mouth of the Obispo it follows the gorges we have described.

The Bench at Mata Chin. — There is some slight evidence of an old planation surface representing an ancient level seen in a high bench surrounding a pointed mountain to the west of Mata Chin. This bench as shown in the accompanying illustration (Fig. 9) is fully 150 feet above

FIGURE 9. Topogaphy in Vicinity of Mata Chin, showing supposed Ancient Bench of Chagres.

the present river, and may be, geomorphically speaking, a continuation and correlative expression of the drainage curve during the period of the Monkey Hill base level. How far up the Chagres similar phenomena may extend cannot be said, but this is the last of the possible planation surfaces indicative of old river history to be seen in crossing the Isthmus. Thirty-three miles from Colon the gradient of

the drainage profile of the Obispo increases, owing to the falls of the river (aggregating 85 feet) which are located at this point. These falls are at the southern end of the narrow gorge marking the Mata Chin section, as it cuts through the eastern perimeter of the circle of hills surrounding the Culebra basin, to be described.

The Culebra Subsection and the Culebra Basin.

From Haut Obispo to the Culebra Pass the country widens out into the great basin or amphitheatre, surrounded on all sides by massive hills not exceeding 500 feet in height, which are composed almost entirely of the basic igneous rocks.[1]

This basin, sub-oval in shape, has its greatest length north and south, and sends out arms or embayments between the larger mountains, the Culebra Pass being one of these. This region is drained by the Obispo and Rio Masiniba.

It is possible that this Culebra basin was once temporarily an enclosed lake, which has become drained by the cutting of a gorge through the volcanic rocks of the north border of the hilly perimeter between Haut and Bas Obispo. When I first ascended the Culebra Mountain, although ignorant of the fact that the Canal Company had formulated a plan to convert this basin into a lake by a dam at the lower end of it, I was impressed by the fact that here had once existed an interior basin similar to those found in many places in the irregular surface of the volcanic summit regions of Costa Rica, Nicaragua, and Guatemala, from which the drainage had escaped through the gorge between Cascadas and Mata Chin.

The Culebra Clays. — The basin portion of the Culebra section is composed of stratified sedimentary clays and other sediments, having an important relation to the Isthmian geology. According to the borings of the Canal Company which I was permitted to examine in the office of the Chef de Section at Culebra, through the kindness of the Director General, these sediments at kilometers 53 and 55 in the Culebra Pass extend downward to at least 25 feet below sea level, the limit of the borings. They contain occasional seams of lignite, and I collected from the lowest cutting of the canal at Culebra Station fragments of fossil plants. These sediments occur between the igneous masses of the adjacent hills of the Culebra summit and Cerro de Lirio,

[1] This is the Culebra basin which it is proposed to convert into an artificial lake by a dam at Bas Obispo. (See Plate XI.)

Cerro Cordo, Cerro Pruja, Cerro Mitra, and Cerro Reyo, which surround the basin. These clays likewise filled the so called Culebra Pass and extend into it, but not far beyond the col, towards the Pacific side. It is their presence which has caused the engineering difficulties accompanying the cutting at this place.

The combined section exposed in the pass between Cerros Lirio and Culebra, and on the slopes of Culebra hill above the lowest cutting in the canal (246 feet) to the summit (623 feet), and brought up by the drillings of the Canal Company from 28 feet below sea level, reveals nearly 500 feet of this clay. The lithologic character can best be seen in the fresh exposures of the latest of the excavations of the Canal Company, in progress while I was upon the ground. They consist of a mixture or rather alternations of laminæ of dark drab clay and sand, and resemble in general aspect the clays of the lower Eocene which have such extensive development through Alabama, Mississippi, Arkansas, and as far south as Tampico in Mexico. They have such an ancient look that I should hesitate to consider them of recent origin.

The following section was made from the lowest diggings of the canal in the Culebra Pass to the summit of Culebra Mountain on the east side of the pass, as shown in the illustration. (See Plate XII.)

Section of the Culebra Pass, beginning at the line of the lowest Canal diggings, January 19, 1895, altitude 246 feet, *to summit of Culebra,* altitude 623 feet.

Cut 1. *a.* Dark brownish black, laminated, unctuous clay shales with alternations of sandy layers, much finely disseminated lignitic matter, and containing imprints of dicotyledonous leaves. These beds are greatly distorted, and have a prevalent dip to north. Canal bottom in these clays. Thickness, 5 feet.

b. Oxidized bed of similar material to *a*, soft earth of mealy consistency, resembling decomposed tuff, with a layer of very small pebbles at base, and an indurated clay layer at top, containing boulders of apparently igneous rock. According to Prof. Wolff this material is a gray tuff, with fragments of feldspar and basic andesitic lava, consisting of a gray agglomerate of small fragments closely pressed together. The cement is a fine chert material with solid grains of black; the feldspar crystals are quite perfect, but the rocks appear to be sedimentary. The small black pebbles fonnd in the clay are, according to Wolff, chert, cherty tuff (with feldspar fragments), silicified tuff with large feldspar fragments, and fine-grained black siliceous shale with feldspar fragments. Thickness, 5 feet.

Cut 2. *c.* Similar beds of clay to 1 and 2. 20 feet.

A few hundred feet east of the line of the above section, in the lowest cutting of the canal (Cuts 1 and 2), two more interbedded sheets of the tufaceous material were observed, both with a strong dip towards the Pacific. These were only a few feet in thickness and one of them was strongly faulted down to the southward. The clays clearly lie against it, and between it and the Cerro Lirio, to the north, which is of a similar nature.

Cut 3. The same clays continue, but are cut by an intrusive sheet of igneous rock.

d. Sedimentary redeposit of igneous rock, dipping south, has fracture of newly broken pig iron. 31–34 feet.

e. Rotten, red, porphyritic looking clays, resembling the decomposed red porphyries in deep mines of Catorce, Mexico. It is evidently material of igneous origin, which has been redeposited by sedimentation, and possesses lamination and stratification. It also shows some indication of being metamorphosed clays.

f. A persistent band of black oxidized material belonging to top of *d*.

g. A band of yellow clay, conchoidal.

Between *d* and *e* there is a thin band of small rounded pebbles. Total of Cut 3, 20 feet.

This section certainly looks as if *d* was intrusive into *a* and *b*, and that *d* is unconformable upon both. *e* is very much cross bedded. Prof. Wolff's examination, however, shows that this igneous material is a sediment.

Cut 4. The embankment of cut 4 is now nearly overgrown with grass, but in places shows thin, black, laminated layers of clay shale, alternating with white layers. The darker layers are very carbonaceous and full of plant stems. 20 feet.

Cut 5. This is a mass of clay similar to cut 4. The clay is creeping down the hillside. 30 feet.

6. Same as cut 5. 30 feet.

Cuts 7 and 8 are towards the north (Colon) end of the mountain. They are mostly deep red residual clay, with large angular blocks of the Culebra Summit igneous rock in them. These beds are apparently different from all the preceding, and very much resemble the hillside boulder clays of Costa Rica.

Above the clay bench (8) marking the north end of the mountain projects the palisaded flat-topped crest of the Culebra Summit. This is a massive black protrusion of igneous rock, and not a lava cap. According to Prof. Wolff, "This is a coarse basalt or melaphyre, corresponding in structure to many of the thick trap sheets of the Mesozoic diabases, palisades, etc. Its coarseness and lack of pores make it probable that it is either an intrusive mass or comes from a very thick flow."

Whether the Culebra clays of the foregoing section are deposited against the igneous mass of the Culebra Summit, or whether the igneous mass was protruded through the clays, are questions which require careful consideration. There are no suitable contacts exposed around the Culebra mass which throw clear light upon this question, owing to the fact that the subaerial decay is so extensive where the two formations come together. The evidence of the sedimentary sills or beds of igneous tuff and agglomerate interbedded with the clays in the lower portion of the section is incontrovertible proof, however, that some igneous intrusion had taken place before the upper portion of the section had been deposited, and I am inclined to believe that the intrusion of the Culebra Summit rock was largely prior to or contemporaneous with the bedding of the clays. The presence of the finely rolled, water-worn igneous

pebble interbedded with the clays themselves in the lowest cuts is also evidence that some of the igneous mass existed during the deposition of these clays.

I was able to trace the Culebra clays as far north on the railroad line as Gorgona, and as far south as the Pacific end of the Culebra Pass, in which direction they abruptly end. Nowhere, however, could I find a contact showing their stratigraphic relations with the other beds, so densely concealed is the surface by residual formations and vegetation, I am convinced, from their geographic position and lithologic resemblance, that they belong to the Eocene Tertiary formations of the Isthmus and near the base of that group. I am also inclined to believe that this is part of the large and extensive coal bearing formation which has been found at many places throughout the entire Isthmian region. These clays certainly extend north to Las Cascadas, where they have exposed a thickness of 150 feet, and where they are again broken through by the Obispo massives. I was informed that similar clays containing coal deposit also occur back of Frijoles Station.

The Empire Limestone.—I had almost completed my section of the Isthmus, and despaired of determining the age of the Culebra clays, when my attention was called to an old lime kiln about two miles north of the Culebra Summit near Empire Station (miles 34.5), where some Italians in former years had erected a lime kiln and burned limestone from the vicinity. This locality was seen and described by Maack. It is almost at the crest of the Culebra Pass, occurring less than two miles north of the so called continental divide, and surrounded for miles on each side by igneous rocks and the clays of the Culebra basin. Mr. Cunningham, Chief Engineer of the railroad, kindly accompanied me to the locality, and we succeeded in finding the ancient kiln, and a small outcrop of the undoubted limestone, massive, semi-crystalline, and yellow-white in color, resembling somewhat the harder limestones of the older Tertiary of the Antilles. Only two small areas of this formation were exposed, in the cutting on the west side of the track, about 10 vertical feet, and below it toward a little creek a small knoll about 20 feet in diameter. The 10 feet of this limestone exposed in the cut added to that of the lower lying mound would indicate at least 50 feet in thickness of the formation. The outcrops show slight angles of inclination and jointing, such as would suggest considerable disturbance. The contacts and relations to all other rocks were so obscured by the thick red clays and vegetation that it was absolutely impossible to trace its extent away from the outcrops. In the creek bottom, about 75 feet below the

limestone, I found the massive igneous rock, but not in direct contact. The laminated clays of the Culebra basin outcrop in the railroad cut about 100 yards to the north of the limestones, but whether it would cover or underlie the outcrop of limestone was a point which was absolutely indeterminable. From the position of these limestones, however, and the apparent regional northward dip, I am inclined to think that, while overlying the portions of clays of the Culebra section, they are merely a local band of limestones in the greater clay series.

Here then, indeed, was an old sedimentary fossiliferous rock near the present continental drainage divide, lying about one and a half miles to the east, the outcrop in fact being only 30 feet lower than the railroad through Culebra Pass, and its fossils would probably throw important light on the age of the Culebra clays and igneous rocks. Searching the outcrops only traces of a few fossils could be found, — a few small oysters and a single Pecten,[1] — none clear enough to afford definite determination. Further study of this material, however, has shown it to contain important microscopic fossils. Sections of the material showed that the limestone is largely made up of foraminifera. Mr. R. M. Bagg, to whom they were referred, says: "Only the slides of No. 14 (the limestone under discussion) were sent, and it is not easy, if possible, to determine anything but generic types in sections alone. These slides, however, contain sections of Nummulites, one Orbitoides, Cristellaria or Rotalia type, and a Nodosaia. It is probably an Eocene rock as in No. 1 (the Foraminiferal marls near Bujio, described on page 177), as the Nummulites are the predominating types."

Thus it will be seen that while there is paleontologic resemblance between this foraminiferal limestone of Empire and the foraminiferal beds of Bujio, yet lithologically the materials are quite different.

The reports of Drs. Dall and Bagg, upon the fossils of the Empire limestone are of value in that they tend to show the apparent Eocene age of the stratified clays to the southward of the Mata Chin section, where direct continuity with the Caribbean section is broken. These beds probably represent a portion of the Eocene series of the Caribbean sedimentaries.

The Pacific Subsection.

The slope of the Culebra Saddle with its accompanying clays continues slightly beyond the two Cerros bordering the pass, when they are abruptly terminated by the sudden descent to the Pacific, ten miles distant.

[1] See Dr. Dall's report.

To describe this configuration as a slope to the Pacific would convey an erroneous impression to the reader, for it is not a coastal slope at all in the ordinary sense of this term, but a rugged hilly country like the central region, which extends straight, not only to the water's edge, but far out across the waters of Panama Bay to the south edge of the continental outline off Morato and Burico Points. Flat swamp-like indentations have been made into this hilly country, by ancient erosion and subsidence. By sedimentation these indentations have been filled with littoral deposits which in turn have again been elevated into low swamp lands, representing ancient embayments or niches in the otherwise rugged coast, the chief of which is Panama Bay, surrounded on three sides by the rough hilly country, and in which stand a few islets of volcanic rock.

FIGURE 10. Naos, Culebra, Perico, Flamenco, San José Rock, Bay of Panama.

Thus it will be seen that, as on the Caribbean side, there is no such feature as a coastal plain uniformly skirting the coast for great distances, but that the rugged topography, except where indented by the Rio Grande swamp level, abruptly terminates at the oceanic waters, and even continues out into the waters of Panama Bay many miles from the shore (Fig. 10), as seen in the islands of Naos, Tobago, Perico, Flamenco, San José, and Changargi,) also see Figs. 12, 13, 14, 15, 16, pages 203, 204,) whose summits and outlines, projecting above the water, are almost in every detail a repetition of the long eroded geography and geology of the mainland with which they undoubtedly were at one time continuous. (See Plate XVIII.) Between the level of the Rio Grande swamp and the rough summit topography of both the mainland and the islands, however, an indistinct but persistent bench could be discerned, representing an ancient base levelled plain, which will be described as the Panama base level.

Looking from the Caribbean side through the Culebra Pass, some low rounded hills of igneous rock can be seen. They apparently constitute a continuation on the Pacific side of the Culebra and Lirio igneous masses. In this hill of igneous rock near Paraiso the actual summit cut of the railroad is located. (See

Plate XIII.) The material is a dark colored tuff, with large enclosures of angular and rounded fragments. From this point on, these rocks are well exposed in the cuts of both the railway and canal, and in the first headwaters cañon of the Rio Grande (at Rio Grande Superior, 37.30 miles) about one kilometer south of Culebra Station, and thence most of the way to Panama Station.

In the deep cuttings near Rio Grande Superior (37.30 miles), this tuff seems to lie above more massive basalts exposed in the great cut made for diverting the railway from the route of the canal. The summit of the hill shows a great thickness of residual (non-stratified) clay.

At Curacacha (38 miles) there are still other cuts in the massive basalt, which continues to Paraiso, 39 miles. Thus it will be seen that for a distance of two miles along the rougher, upper portion of the descent to the Pacific extending from the summit pass to Paraiso, as determined by Prof. Wolff's examination of the specimens, the railway and canal run mostly through diabase, or coarse basalt, similar to the summit of Culebra Mountain, together with alternations of dolerite, and a "dirty gray tuff, containing fragments of glassy basalt."

At Paraiso is seen the first evidence of a formation which, appearing at various places along the Pacific coast, becomes of great importance in the Isthmian story, and which will presently be described more fully. This consists of an ancient looking whitish conglomerate.

Near Pedro Miguel (40.34 miles) another outcrop of this material is seen resting on the basalt. The road now reaches the interior end of the swamp level plain which indents the rugged hills from Panama to this point.

The Miraflores Pumice. — At Miraflores in the bluffs bordering the valley of the swamp level plain (Colon, 41.69 miles) there is a clean cut

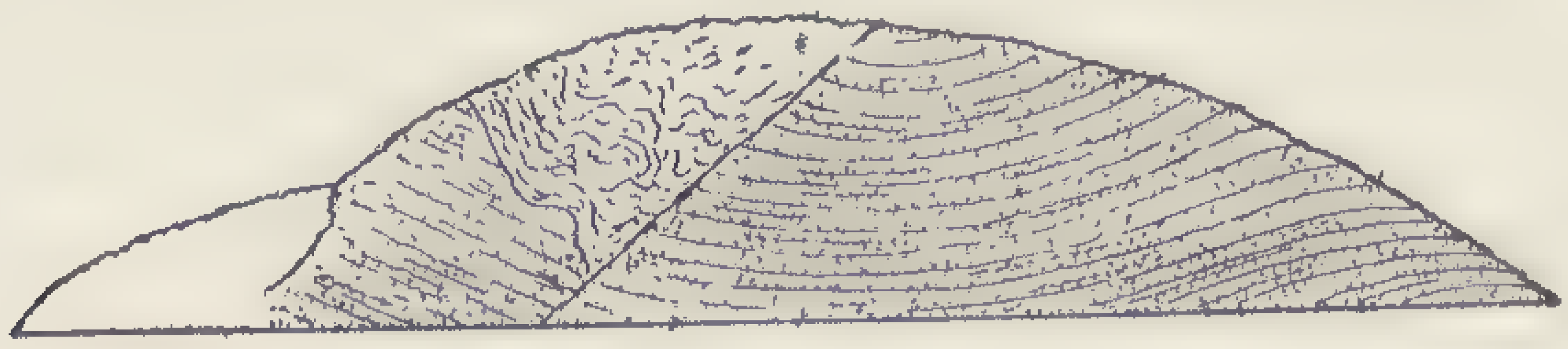

FIGURE 11. Section at Miraflores, showing Disturbances.

vertical section (see Fig. 10) through a hill of peculiar material. With the exception of the conglomerates above mentioned this is the first outcrop and the only clear exposure of apparently sedimentary rocks between the Culebra Summit and Panama. The vertical face of the cliff is about

50 feet, and the length of the section is 200 feet. The rock is apparently stratified and shows pink, salmon, and magenta colors similar to those seen in the Potomac formation of the Eastern United States. The material resembles a fine light grained clay sandstone, but is singularly free from grit. These rocks are indurated on the surface, and strongly oxidized. No traces of fossils could be found. There are strong synclinal and anticlinal folds cut by vertical faults, showing clearly that the rock has been subjected to serious displacement since its formation. This outcrop is important, inasmuch as it is on the flanks of the Pacific side of the great igneous masses of the Isthmus, and, as will be later shown, has a strong and suggestive relation to the Barbacoas formation of the Atlantic side. (See Panama Formation, page 200.)

The Panama Swamp Levels. — Past the outcrop at Miraflores the road descends into the old alluvial sedimentary level valley or swamps of the Rio Grande, above the level of which project at various intervals hills of igneous rocks. These swamp levels are singularly like those of the Caribbean side, and are irregular indentations into the rugged coast topography.

The swamp lands lie on all except the ocean side of the Cerro Ançon, a great rounded mountain, estimated to be 600 feet high, against the foot of which the city of Panama is built. Maack notes the occurrence of recent shells in these swamp lands at numerous places around Panama, coextensive with their extent, which shows that they, like the Caribbean swamps, are elevated marine sediments rather than recently base levelled plains.

Between Rio Grande (43 miles) and Carosal (44.17 miles) other small hills of decomposing basalt rise above the swamp level of the Rio Grande bottom.

From Carosal on to Panama the road follows the wide flat swamp level plain or playa, surrounded by the Culebra hills on the east and north, and the great Cerro Ançon upon the west, around the north end of which the Rio Grande is deflected, reaching the Pacific about three miles west of the city.

The Cerro Ançon. — This peculiar isolated eminence, separated by the Rio Grande swamp level from the Culebra group of summits, certainly presents a topographic aspect far different from that of any other summit seen by me in the region, its less pointed and more rounded mammillary shape being in strong contrast with the peaked summits of both the mainland and adjacent islands elsewhere seen, and strongly suggests that it is of a different composition, not only

from the outcrops I saw just above its base, but from all the other mountains of the central igneous region.

I endeavored to ascertain the geologic structure of Cerro Ançon, but owing to the dense vegetation and residual soil no exposures of bed rock could be found, except at the Canal Company's hospital on the north side and along the water front upon the south. At both localities outcrops extend to about 100 feet above the base of the mountain. The only rocks exposed were highly disturbed stratified material of greenish white color which is later described as the Panama formation. Neither Maack nor other explorers have succeeded in ascertaining the material composing the higher slopes of the mountain.

The Panama Formation. — A formation analogous to the beds at Miraflores occurs along the Pacific coast in the city of Panama and in the adjacent islands. At Panama it constitutes the steep bluff at the water front, as well as the strip of land extending eastward toward the mouth of the canal at the foot of Cerro Ançon. This same rock also outcrops upon the island of Naos, four miles out in Panama Bay.

The geologic composition of the material at Panama is a greenish white stratified fine grained material resembling sandstone with occasional beds of conglomerate. These beds are quite strongly flexed, similarly to those at Miraflores, indicating that they have undergone considerable disturbance since their original deposition. No traces of fossils could be found, nor other evidence affording the least indication of the age of this material, or its relation to the other sedimentaries. Maack[1] has described the material of the Panama formation, and Mr. Garella[2] also noted it.

The specimens collected by the writer from this peculiar formation were submitted to both Professor Wolff and Mr. Turner for determination. Mr. Turner says concerning it: —

"The specimen No. 45, from the Panama Cemetery Gate, is of volcanic origin. The rock has a micro-crystalline feldspathic groundmass in which are embedded abundant broken feldspars, with a few showing idiomorphic outlines. Many of the feldspars are twinned on the albite law, and as their index of refraction is less than that of the balsam, these twinned feldspars are albite. No original meta-silicates were seen, but there are patches and spots of a green secondary pleochroic substance, probably in part chlorite, in one patch of which

[1] *Op. cit.*, page 164.

[2] Project of a Canal to connect the Atlantic and Pacific Oceans across the Isthmus of Panama, by Napoleon Garella, Engineer in Chief of the Royal Corps of Miners. Rep. No. 145, U. S. House Rep., February 20, 1849, page 520.

are embedded divergent feldspar laths, resembling the ophitic structure, except that the green material does not have the same orientation throughout, but is composed of optically independent grains. The interference colors of some of this green material were too high for chlorite, suggesting that it may be chlorite in which are embedded minute hornblende fibres. The exact nature of this volcanic material is not apparent from this cursory examination, but the appended chemical analysis of the freshest part of the specimen made by Mr. Steiger indicates that it is probably of andesitic origin, unless it is badly decomposed." The microscopic examination however indicates that it is a soda-rhyolite-tuff or soda-trachyte-tuff.

"*Analysis of Volcanic Material from the Panama Cemetery Gate.*

(No. 45.)

Silica	65.52
Potassa	2.58
Soda	1.99

"No. 20, from Miraflores Station, five miles from Panama. From an outcrop resembling disturbed and metamorphosed clays. This is a fine grained reddish sedimentary (?) rock. Microscopic examination shows it to be composed chiefly of minute grains that appear to be feldspar, with a few scattered larger feldspars. Much of it is discolored by a white and yellowish decomposition product of the nature of clay. It is possibly a feldspathic tuff. It is evidently undergoing decomposition to clay."

Professor Wolff says concerning this material, that "No. 20, Miraflores, and 23 and 36, Barbacoas, are the same. I have concluded that they are composed of an acid rhyolitic pumice much like that found in beds in some of the Western States. Also 37, San Pablo."

From the report of Professor Wolff it will be seen that the Miraflores formation (which is the same as the Panama) strongly resembles the Barbacoas formation upon the opposite side of the Isthmus, while Mr. Turner likewise correlates them. Thus we have flanking both sides of the central igneous section an extensive deposit of apparently related formation quite different from the basic volcanic rocks. Upon the Atlantic side the testimony is clear that this formation was made previous to Bujio tuffs of the Tejon-Claiborne epoch of the Eocene fossiliferous sedimentaries, while upon the Pacific side the contacts show that it has been pushed up, distorted, and broken through by the intrusion of the basic igneous rocks of supposedly Eocene age of the central section.

The composition of these rocks also probably indicates that they were formed before the great basic igneous outbursts of Tertiary and later times. They are largely made up of free quartz grains and feldspars, such as do not occur in the later igneous rocks, and no formation since

the period of basic igneous eruptivity could possibly have been deposited so free from its characteristic débris. Besides, there are no known Post-Cretaceous areas of quartzitic rocks now exposed throughout the region from which such acidic formations could have been derived in Tertiary or later time. Hence I am inclined to think that the Panama formation represents a remnant of the older Pre-Tertiary rocks of the Isthmian region. It is an interesting fact, also, that both Garella and Maack considered these rocks described by them as conglomerates and sandstones of Pre-Cretaceous age.[1]

The Panama formation certainly has, as Maack and Garella have previously stated, the colors and stratigraphic appearance of the older Mesozoic sandstones, both of Europe and the Western United States, but age conclusions cannot be drawn from such lithologic resemblances.

The Panama Bench or Base Levelled Plain. — Around the base of Cerro Ançon, bordering Panama Bay, is a low hilly bench standing at an average height of about 75 feet above the level of the sea and the swamps, and forming a low shoulder between it and the sea. The rolling summit of this bench, cut by numerous drainage lines which cross it, is traceable between the mountains and the sea eastward from Panama toward the mouth of the Rio Grande and the canal, the city proper and outlying cemeteries being built upon it. Beyond the Rio Grande it extends eastward at intervals for twenty or thirty miles, and may be traced a still greater distance. From its irregular summit to the waters of the bay there is in places a sharp escarpment or bluff which is being undermined by the waves at high tide, and its débris distributed over the surf line of the bay. The extreme seaward point of Panama, upon which the military post is located, is of this nature.

This bench is an old base levelled plain, reduced to its present topographic aspect in past geologic time, when the coast was much lower than at present, and taken in connection with the lower Rio Grande swamp level presents a remarkable historic analogy to the corresponding features of the Monkey Hill base levelled plain and Mindi swamp level of the Caribbean side, which, when taken together, testify that the Isthmus has most certainly participated in certain uniform (Epeirogenic) movements, in addition to the disturbances of volcanic orogenic (wrinkling) character. It will be seen as we proceed that the Panama base level is a persistent feature in the Costa Rican and Panama region, and is well developed upon the islands both of Panama Bay and the Pacific, and the adjacent coast of the mainland at least as far as Punta Arenas in Costa Rica.

[1] *Op. cit.*, page 164.

Panama Bay.

Although we have now passed from the Caribbean to the Pacific, the continental section is not yet completed, for its features continue southward, twice as far, across the waters and islands of the Gulf of Panama. This great pouch-like indentation into the southern coast of the Isthmus of Panama, 100 miles long, is exceedingly shallow, hardly reaching 50 fathoms in depth until we cross an imaginary line drawn between the opposing headlands marking the entrance to the Gulf. (See Plate VI.) Beyond this line, which is a continuation of the shores of the most southerly mainland bordering the Pacific, the submarine profile makes a sudden plunge of from 50 to 1,800 fathoms or more. Thus it will be seen that the bottom of the Gulf of Panama is really but a few feet below the present level of the sea, and a slight elevation would convert the whole bay into a rugged land area similar to that of the present mainland.

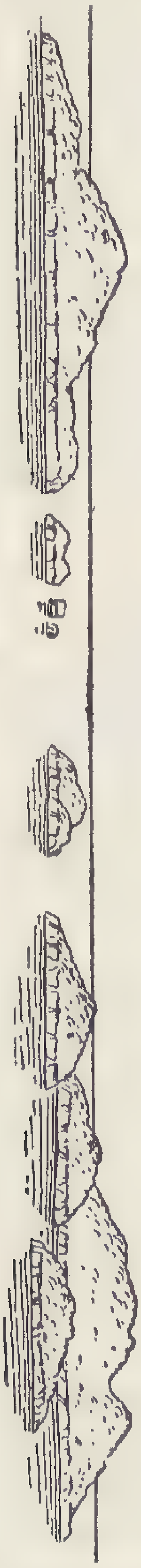

Figure 12. Taboga and Taboguilla.

Figure 13. Taboga Island and outlying Rocks.

Furthermore, this great gulf is marked by numerous islands and islets rising above this submarine platform of the bay. Some of the summits rise higher than that of Culebra, the so called continental backbone. The highest of the eleven pointed hills of Tobago Island is nearly a thousand feet in altitude (exactly 935 feet), while the adjacent Tobaguilla is 710 feet.

The intervening floor of the bay between these islands and the mainland, only a few miles distant, is but seven fathoms (42 feet) in depth. Still farther out into the bay the group constituting the Pearl Islands present the same rugged Panamic topography, the points rising to various altitudes, some of them as high as 600 feet.

The accompanying sketches (Figs. 12–16) illustrate the topography of the islands of Panama Bay.

The highest of these islands are marked by three conspicuous features, all of which are likewise characteristic of the mainland. The first of these is the rounded and pointed character of the higher summits, exactly analogous to those of the central portion of the Isthmus. Upon most of the islands where these high summits exist, their lower profiles expand horizontally into distinct extensive benches or shoulders, standing about 75 feet above the water at the sea line. These shoulders, together with the entire summits of some of the other islands, where the high pointed hills are missing, undoubtedly represent the Panama base levelled plain of the mainland.

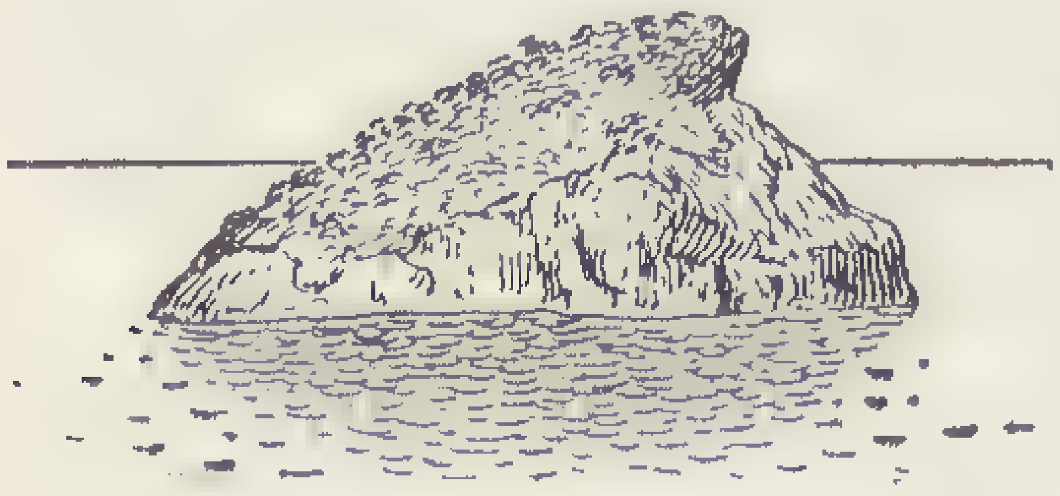

FIGURE 14. Guano covered Rock, near South End of Taboguilla Island.

These island benches correspond to the Panama plain, and are terminated abruptly by steep vertical cliffs at the water's edge, corresponding in height to the tidal variation of about 20 feet. These cliffs are often concave in profile, and it is apparent upon every side that they are produced by the intense wave erosion which is at present rapidly undermining them. Frequently the beating of the waves has cut a narrow passage through some projecting cape, completely severing small islets from the larger body with which it was but recently connected. Every stage in this process can be seen in various places. It seems to me that:—

FIGURE 15. San José Rock, Panama Bay, Remnant of Panama Base Level.

1. All of the islands of Panama Bay are composed in part of the ancient looking, black igneous rock, apparently of the same character as those found upon the Isthmus, interassociated with the Panama formation, which can be seen upon the island of Naos outcropping close to the water, as at the city of Panama.

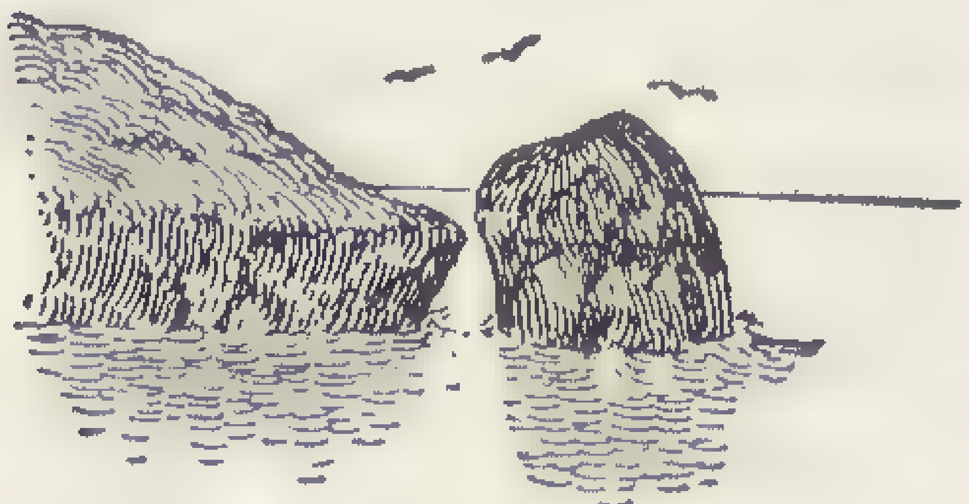

FIGURE 16. Basaltic Rock, South End of Taboguilla Island.

2. They are all ancient rocks, and nowhere present original surfaces of extrusion, or evidences of volcanic vents.

A single glance at these islands conveys two important suggestions: 1. Their topographic forms and geologic structure are essentially those of the adjacent land, of which apparently they were once a part, and have been severed from it by subsidence or marine erosion. 2. Conversely, in looking at them one is impressed with the fact that a few feet of submergence would convert the entire mainland of pointed hills and drainage valleys into exactly similar islands. They undoubtedly represent the remnant of what was no doubt once a continuous stretch of land over the area now occupied by the gulf.

A comparison of the illustrations of this partially drowned topography of Panama Bay with that of the Puerto Bello coast of the mainland on the Caribbean side (see Fig. 1, page 156) shows that it would require but little subsidence and erosion to submerge the valleys and to convert the Puerto Bello summits into islands like those of Panama Bay.

Résumé and Conclusions concerning the Isthmian Section.

Having described the details of the general section across the Isthmus and the Gulf of Panama, let us examine it in order to ascertain what light it throws upon the Isthmian and continental history.

For convenience the section has been arbitrarily divided in the several subsections under which its detailed geology has been discussed. In all there are seven conspicuous structural units to be noted: 1. The fringing coral reefs; 2. The coastal swamps of both coasts, which are elevated plains of sedimentation; 3. The Monkey Hill and Panama benches, which are elevated base levelled plains of erosion; 4. The folded and disturbed Tertiaries, which belong to a series of Post-Tertiary orogenic foldings along the Caribbean side of a more ancient nucleal region; 5. The numerous protrusions of basic igneous rocks which extend back into undetermined antiquity; 6. The sedimentary rhyolitic and andesitic tuffs of Barbacoas, San Pablo, Panama, and Miraflores, herein called the Panama formation, which in age precede the basic igneous formations; 7. The granitic rocks, which, as indicated by the detritus brought down by the Chagres, must occur *in situ* to the east of our section.

Classification of the Sedimentary Rocks. — The sedimentary rocks of the section may again be classified by formation into three categories, viz.: (1) Those supposedly of Pre-Eocene age occurring on both the

Caribbean and Pacific sides of the Isthmus. (2) The fossiliferous Tertiary beds of the Caribbean side. (3) The Pleistocene beds deposited synchronously on both sides.

Of the first class the only rocks found were those of the so-called Panama formation, which name will now be used to include the analogous deposits of Barbacoas, San Pablo, and Miraflores. These, as has been stated, are so distorted and concealed by later igneous protrusions and deposits, that almost nothing can be ascertained of their antecedent relations. Lithologically they certainly disagree in every generic character from the Tertiary and Pleistocene sediments. They are composed almost entirely of rhyolitic and andesitic volcanic material, of whitish colors singularly free from the darker basic igneous minerals and the ferruginous, bituminous, and glauconitic colors everywhere so abundant in the later formations. The principal discoloration is a light greenish tint, occurring sparsely, as if the chloritic element was but faintly developed in the rocks.

There are other facts which lead me to believe that these rocks belong to a much older series than those of the fossiliferous Tertiary sediments, and that they are a part of an extensive Pre-Tertiary formation, which has been largely concealed by the later events, and which occurs widely beneath the volcanic débris of Panama and Costa Rica. In the peninsula of Nicoya, and where erosion has cut down to the very base of the plateau of Costa Rica, there is a great series of rocks which have such petrographic resemblance to this Panama formation that I am prone to believe they are of the same epoch.

The fossiliferous Tertiary sediments, including the Culebra, Empire, Gatun, Vamos á Vamos, Mindi, and Monkey Hill formations, I consider to have been deposited along a littoral margin of the Caribbean Sea. These sedimentaries are of the Eocene and Oligocene epochs of the Tertiary. The beds of this series containing marine fossils, according to Dr. Dall's determinations, like those of the Claiborne-Tejon epochs of the Eocene, the Vicksburg Oligocene of the United States, and the Caribbean Oligocene; the last corresponds paleontologically with a group of sediments now found around the peripheral lands of the Caribbean in the Bowden beds of the Great Antilles, Trinidad, Curaçoa, and in the Chipola beds of West Florida.

As in the United States, the Tertiary rocks of the Caribbean side seem to represent an aggregation of muddy sediments composed of impure mixtures of sand and clay, accompanied by glauconitic and lignitic material derived from the plants deposited contemporaneously

with them. There are only two limestone horizons in this series. One of these, the concretions of Vamos á Vamos, are of a secondary concretionary nature, largely mixed with volcanic débris, and the other — the Empire formation — according to Dr. Dall "has the appearance of the Everglades limestone of Florida, and has in part been deposited or recrystallized from a solution." With this exception masses of chalky or marine limestones of organic origin are conspicuously missing.

In discussing this Tertiary series as a whole we are confronted at the outset by uncertainty as to what constitutes its oldest beds. This confusion is created by the lack of final and conclusive evidence upon the stratigraphic position of the Culebra clays. It is my firm conviction, however, founded upon the general lithologic aspect of the Tertiary series of the Atlantic side and from their lay, inasmuch as we encounter newer and newer strata toward the Atlantic, that the Culebra clays represent the base of the Tertiary series of the Isthmus. The Empire foraminifera are closely allied in age to those of Bujio, and hence it is but fair to conclude that the still lower lying Culebra clays belong to the earlier stage of this epoch of the Eocene. If my hypothesis be true that these clays are at the base of the Tertiary series, then it is probable that they belong to the earliest Eocene period. The Vamos á Vamos beds, according to Dr. Dall's determination, are undoubtedly of Claibornian Eocene. Unfortunately the exact stratigraphic position of the foraminiferal beds of Bujio is concealed. From their position in the folded complex, I believe that they are below the Vamos beds. Dr. Dall, however, is of the opinion that the fossil foraminifera indicate that they belong above the latter, but from my observations upon the range of these forms in Jamaica, I believe my position the most tenable.

The undoubtedly fossiliferous Tertiary beds lying above the Culebra clays occur in three or possibly four well defined subdivisions. The oldest or lowest of these are the Empire limestones, composed so largely, as we have shown, of foraminiferal remains.

In the Vamos á Vamos beds we find the first display of a rich marine molluscan fauna, which gives a positive clue to geologic age. When I first saw the bluffs containing these fossils I thought they were igneous outcrops, so black was the color of the impure rocks, which, as shown by the petrographic investigations of Professors Wolff and Turner, is the result of the mixture of basic igneous material in them. Professor Wolff describes this rock as "a dark gray limestone containing shells in a calcareous cement containing fragments of hornblende, triclinic feldspar, and augite from andesitic lava." Evidently, from this descrip-

tion vulcanism was active in the Isthmian region prior to or during this epoch.

An important change in the sedimentation of the Tertiary beds must now be noted. The impure character of the Vamos á Vamos beds suddenly changes into an extensive uniform formation of greensand marl of the Mindi Hill beds, as is shown by the exposures in the Mindi, Monkey Hill, and Derivation cuts. Dr. Dall naturally thinks that this change of sediment indicates that these later beds are the more finely triturated material deposited in slightly deeper waters, but inasmuch as the fossils are the same as those of the Vamos á Vamos formation, I am inclined to believe that the difference is due to the fact that the Mindi sediments no longer received in their composition the volcanic material which was freely intermingled with the lower lying Vamos á Vamos beds during a contemporaneous active igneous epoch. In other words, this change gives a clue as to the time of the cessation of the Eocene igneous activity.

The Monkey Hill beds, which lithologically resemble the Mindi beds and apparently belong to the same cycle of sedimentation, have a fauna which shows that they are of later age, being equivalent, according to Dall, to a lower Miocene (Upper Oligocene) fauna which has wide distribution in the Caribbean region, such as are found in Curaçoa, Haiti, the Bowden beds of Jamaica, and the Chipola beds of Florida.

The foregoing mentioned Isthmian beds, so far as known, constitute a great and continuous epoch of sedimentation, embracing the Eocene and Oligocene epochs.

One of the most instructive points in the Tertiary section is its abrupt termination with the early Miocene, indicating a great geomorphic change, following that period. No trace is preserved to indicate that sedimentation occurred on the area of the present Isthmian region during the late Miocene and Pliocene epoch, and the only legitimate inference, fortified by other lines of evidence, is that the Isthmian land was of much larger area during these later epochs than in Eocene time or at present.

The thickness of the Tertiary rocks in the Caribbean section is difficult to estimate. At least six hundred feet of outcrop is directly exposed in the various hills, but it is impossible to estimate the thickness of that which is concealed. A thousand feet would represent the minimum approximate thickness, but it may have been double or tenfold this.

The fossils of the late sedimentation of the swamp levels of both sides of the Isthmus show that these beds are marine littorals of late Pleisto-

cene or recent age; as also are the elevated coral reefs of Colon, composed of common Caribbean species.

The Igneous Rocks. — The igneous rocks in this section of the Isthmus and their sequence may be grouped as follows: —

1. The granites, constituting the massifs of the east and west Cordilleras of San Blas or Choco, which borders the coast from Puerto Bello eastward, the rocks of which have been mentioned by many writers, and the gravels which are brought down so abundantly by the Chagres from its headwaters.

2. The rhyolitic tuffs and pumice occurring on both sides of the Isthmus, as the Panama and Miraflores formations of the Pacific coast and islands, and as the Barbacoas and San Pablo formations of the Barbacoas section. The materials composing the formations are undoubtedly sedimentary in arrangement, but primarily igneous in origin. All known data indicate that they were produced during a period of acidic eruption previous to the extrusion of the basic igneous rocks, and before the Eocene period.

3. The third igneous group comprises the basic igneous rocks, — occurring as intrusives, eruptives, tuffs, and rolled débris, consisting of basic eruptives, — including basalts (olivine, diabases, and dolerites), augites (both andesitic and porphyritic), and trachyte tuffs of similar materials, and one boulder bluff of hornblende augite, andesite, or porphyrite. These rocks occur *in situ* between Mamei and the extreme south coast of Panama parallel to the outer margin of the Gulf. While they undoubtedly represent different eruptive events, they practically belong to one generic epoch, which might be termed the period of the basic eruptives. The more massive basic intrusives were first pushed through the older Panama (Barbacoas) formation, and their rolled débris subsequently transported, distributed, and deposited over the latter. This débris makes its earlier positive occurrence as the Bujio conglomerate, the age of which can definitely be placed during that portion of the early Tertiary as immediately preceding the Claiborne (Vamos á Vamos) epoch of the Eocene Tertiary, the fossiliferous beds of which now lie upon and contain the débris of this older period of igneous extrusion.

Age of the Basic Igneous Rocks. — Structurally the section indicates that there was a great area of basic igneous eruption, the cross section of which reached from one hundred miles south of Panama, in line with the points of Panama Bay, to the Mamei, near the geographic centre of the Isthmus. The former elevations which these igneous intrusions attained, through the vicissitudes natural to its greater area, have,

through atmospheric and marine erosion, nearly all been degraded to marine base level. That the basic igneous rocks did not originate in recent time has been shown. Nowhere on the portion of the Isthmus visited by the writer did he find overcapping flows of the igneous rocks resting upon the Tertiary or later strata, except in the case of those in Panama Bay, and the connection of these with the central igneous protrusious was not proven. While there is sufficient variation in the character of these rocks to indicate that they represent more than one outburst, their lithologic composition as a group is different from the later volcanic ejecta of the adjacent region of Costa Rica, from whence lavas have flown in Post-Tertiary time, as will be shown. None of the newer and more recent-looking igneous rocks encountered in my journey across Costa Rica were seen upon the Isthmus, although the older basement igneous rocks upon which the later volcanic phenomena of Costa Rica are built up are quite analogous.

We have shown that these basic rocks were clearly pushed through the older Pre-Tertiary Panama formation at Miraflores. The rolled débris interstratified with Culebra clays show that the clays are newer and later than some of the igneous rocks which had previously existed in that vicinity. The immense beds of rolled igneous boulders found immediately beneath the Vamos á Vamos beds certainly show that a great mass of igneous rock existed before the latter were deposited in late Eocene time.

The occurrence of basic igneous material intermixed in the fossiliferous sediments in the Eocene Tertiary rocks of Bujio and Vamos á Vamos, and the unconformable position of the latter upon the stratified basic igneous conglomerates of Bujio and Pena Negra, shows that these igneous rocks existed during or prior to the deposition of these later Eocene sediments.

If the Empire limestone and the foraminiferal beds of Bujio, containing apparently the same fauna, are of approximately synchronous age, then the difference in composition of the imbedding material gives a clue to one of the great basic eruptive periods of the Isthmian region, for between these outcrops occurs an immense thickness of volcanic boulders and tuffs of the basic igneous rocks. The foraminiferal Empire limestones are apparently free from igneous material, while the equally foraminiferal deposits of the canal section, between kilometer 20 and kilometer 25, lying upon the top of the interstratified volcanic rocks of the Bujio distinctly show the presence of a great amount of contemporaneously deposited eruptive material in their composition. These

facts strengthen our inference that the most marked volcanic episode of the Isthmian region took place during the late Eocene epoch.

The excessive occurrence of this igneous material in the sedimentary Eocene formations of the foraminiferal marls and Vamos á Vamos formation below Bujio, may be accounted for by one of two hypotheses. It was either "wash" from pre-existing igneous masses, or contemporaneously ejected from active vents. The suddenness with which the abundance of the material ceases, as shown by its absence in the Mindi beds, gives preference to the latter theory.

Late Tertiary "Syenitic" Intrusions. — There is every reason to believe that, in addition to the older granites and basic extrusions we have described, there is a line of pseudo granitic or syenitic rocks exposed in the mountains of eastern Costa Rica, the San Blas, and around Sierra del Marta, and the Antilles, which have been pushed up into the Tertiary strata, and now form the core of great mountainous protuberances. The evidence concerning the existence of these rocks is as follows.

The axis of the chain of high peaks of eastern Costa Rica rising to 11,000 feet, according to Gabb,[1] is composed of a granitoid mass which has been pushed up through the Tertiary strata.

Unfortunately no specimens are available by which the exact mineralogic nature of these rocks can be verified. Mr. Gabb says:[2] —

"This rock is decidedly syenitic in structure, containing almost no mica but an abundance of hornblende, resembling closely a similar rock which I found abundantly and under like circumstances in the island of Santo Domingo. It is usually, however, of finer grain than the West Indian rock, and in the manner of its relation to the overlying rocks, it differs in rarely or never sending out dykes through them. . . .

"The granite mass runs to the east in the form of a long narrow tongue leaving the high ridge of the Cordillera, which trends to the southeast, and finally disappears under the (Tertiary) slates, just before reaching the Tilori River. To the northwest it follows the general direction of the mountain summits in a valley of from three to five miles wide on the Talamanca side."

A similar occurrence of apparently the same kind of rock occurs near the coast of San Blas, as can be ascertained from the detailed itineraries and surveys of Messrs. Carson and Bowditch, who accompanied the Selfridge explorations.[3]

Cross sections, via the drainage ways and dividing cols, across these

[1] Unpublished MSS. in library of U. S. Geological Survey.

[2] Ibid.

[3] See Reports of Carson and Bowditch, p. 118. Report of Explorations and Surveys for a Ship Canal, Isthmus of Darien, by T. O. Selfridge, U. S. N., 1870.

mountains from the Gulf of San Blas and Caledonia Bay give the impression that the country is composed of the older Tertiary sandstone and clays which have been vertically folded and through which has been pushed a mass of "syenite." Furthermore the so called "syenite" is cut by dykes of basic igneous rocks. This "syenitic" axis of the Cordillera San Blas is some fourteen miles in width, extends in an east and west direction, and is bordered on both sides by the sandstones and clays through which it has been intruded.

The "syenite" is described as a "hard gray dense syenite, portions of which have a very fine grained and beautiful texture." In places the rock is homogeneous in character; at others it shows veins of quartz and large crystals of feldspar, and at one end is made up entirely of greenstone." These geologists concluded[1] that the "entire nucleus of all the mountains was syenitic, a fact fully verified at many points." The Tertiary sandstones in places are highly metamorphosed, forming a quartzite.

Around Santa Marta, longitude 74°, just east of the mouth of the Magdalena, the Sierra Nevada is largely composed of eruptive granite, described by both Sievers and Karsten. According to the latter,[2] it appears that this granite has been erupted, has come from the depths in an incandescent state, and has elevated, folded, and dismembered the adjacent beds."

Similar "granitic" and "syenitic" rocks intruding the Tertiary strata have been reported in Jamaica by the official surveyors,[3] which occurrence the writer has had opportunity to study.

These many independent observations indicate a wide occurrence throughout the Tropical American mainland and the great Antilles of a Mid-Tertiary intrusive rock which has been considered granite or syenite.[4] In the forthcoming report upon Jamaica the influence of this event in Tropical American geologic history, having great bearing upon the origin of the Antillean mountain system, will be described more completely. In Cuba and Hayti there are probably older granites.

[1] Carson and Bowditch, p. 137.

[2] Géologie de l'Ancienne Colombie Bolivarienne, Berlin, 1886, p. 23.

[3] Memoir Geological Survey of Great Britain. Reports on the Geology of Jamaica. London, 1869.

[4] Mr. Whitman Cross, of the United States Geological Survey, who has studied specimens of this material collected by the writer from the Blue Mountains of Jamaica, describes it as "near the line between granite porphyry and quartz diorite porphyry, . . . of the structural type very common in the laccolithic masses and intrusive sheets of early Tertiary age in Colorado."

The evidence summarized indicates that the volcanic extrusions of the Isthmian section occurred largely during or at the close of Eocene time, although it is probable that some took place in the preceding Cretaceous epoch. Although igneous action may have continued through the Eocene into later epochs, the sudden disappearance of igneous débris in the Upper Oligocene beds is against the latter conclusion. The Eocene was undoubtedly the period of time when igneous phenomena were most actively effective in the Isthmian region. We will show that the Tertiary series in adjacent Costa Rica, however, has been protruded through by still later eruptions, as shown by the studies of Gabb and Sjögren and the writer, and that these Post-Tertiary eruptives of Costa Rica are largely of different petrographic species from the older Isthmian rocks.

The Post-Oligocene Folds of the Antillean Mountain System. — The sedimentation of the Eocene and Oligocene epochs was followed by great deformation, resulting from orogenic folding, the axes of which are in east and west directions, and which were probably accompanied by the deep seated "syenitic" intrusions.

The time of this folding, by analysis, can be approximately located as follows. The sediments composing the disturbed strata were in process of deposition in Eocene and Oligocene time, hence this folding must have taken place at a subsequent period. Likewise, it is apparent that the present horizontal Pleistocene sediments are deposited unconformably against the previously folded Oligocene strata. Hence the period of mountain making must have preceded the Pleistocene. There remains, then, only the late Miocene and Pliocene epochs to which this folding can be assigned. The absence of sediments belonging to either the late Miocene or Pliocene epochs on the Caribbean coast of Panama, and the evidences of long erosion with probable elevations during these intervals, force the conclusion that the time of the disturbance must be assigned to one of these sub-periods, or possibly both. The occurrence in Costa Rica of Pliocene sediments along the coastal margin, unconformably against the older folded Tertiary land, leads to the final conclusion that this epoch of mountain folding must have been in late Miocene time.

Erosion and Base Levelling of the Later Tertiary Epochs. — The evidence indicates that the Tertiary beds suffered much denudation and base levelling during the interval between the great orogenic revolution of late Tertiary time and previous to the swamp level sedimentation of the Pleistocene epoch. This erosion epoch was marked by the cut-

ting out of the greater stream valleys and the creation of the Monkey Hill and Panama base levels, which then marked the sea margin. The now drowned topography of Panama Bay is probably a remnant of this old erosion epoch.

The Monkey Hill and Panama benches on opposite sides of the Isthmus are old base levelled plains of erosion, which, near the close of the Miocene, as closely as can be approximated, were at the level of the sea, and were partially elevated to their present height during the succeeding epochs, for their continuity has been cut through by the Pre-Pleistocene erosion valleys. The epoch of late Miocene and Pliocene erosion was followed by a period of slight subsidence in Pleistocene time.

The marine swamp-level formations clearly occupy the old (Pliocene) valleys eroded out of the late Tertiary topography, which through subsidence were invaded by the sea during the epoch of their deposition, but it is positively shown that these valleys did not transgress the continental barrier. There can be little doubt that the great Panama Gulf was largely submerged during this epoch of subsidence. A general lowering of the land after a period of extensive base levelling is the only method by which this peculiar body of water can be accounted for.

The present position of the contemporaneous Pleistocene sedimentaries of the swamp-level beds on both sides of the Isthmus show that since Pleistocene, or even during recent time, an epeirogenic uplift or uplifts have elevated the whole region at least ten feet above their previous level of deposition. This elevation of the swamp levels above the ocean in Post-Pleistocene time is the last epoch of Isthmian history recorded in this section.

But in spite of much information obtained upon many hitherto obscured points we are unable to give a complete interpretation of the history of the Isthmian region. From the fossils we can only see as far back in geologic time as the Eocene, and these point out only one brief epoch when there could have been connection, although there are non-fossiliferous formations antedating that age. The structure, so far as known, and when considered alone, gives no information as to the period of geologic time when the waters of the two oceans connected across the isthmus. In the Panamic section I found no continuity of beds from the Caribbean to the Pacific side, which would positively prove the former existence of a free oceanic strait. The Empire limestones, the great accumulation of boulder conglomerates, the foraminif-

eral beds of the Mamelon, the Vamos á Vamos, and the Mindi marls, have no representation on the Pacific coast that I could find.

The Panama (Barbacoas) formation is the only sedimentary rock common to the Caribbean and Pacific sides of the present continental drainage divide. The basic igneous rocks are common to the whole area.

The late Eocene and Oligocene (early Miocene) beds are undoubtedly Caribbean sediments, and no structural evidence has been found that they were deposited completely across the present area of Isthmian land. Their composition, which includes volcanic débris and plant remains, is such as to indicate that they represent the littoral débris of a more extensive land which once existed, especially to the southward in the direction of the Pacific.

The Pleistocene or recent elevated coral reefs of the Caribbean side as shown by Verrill are composed entirely of Atlantic species.

Red Clays. — The classification of the surface red clay which conceals all the formations of the Isthmus has caused the greatest perplexity. The sub-aerial decay of the rocks on the Isthmus is simply enormous, extending often to a depth of over 100 and seldom less than 50 feet. The excessive rainfall and immense quantity of vegetal humus and carbonic acid have no doubt expedited this sub-aerial decomposition. In fact this decay is so great that the whole country is covered with a mantle of red clay. It is largely the local residuum of the underlying rocks, the basic igneous rocks, the Culebra clay, the greensand marls of the Tertiary, the alluvial clays of the rivers, or whatever particular formation they may locally overlie. In most regions which I have previously examined I have become able, by studying the character and gradations of the residual material at the surface, to learn properly to associate it with the underlying formation from which it had been derived; but upon the Isthmus I never became able to do so, and could only distinguish their relations by the aid of artificial cuttings revealing gradation into the underlying substructure. In extensive areas where no exposures of the substructure are visible their geologic interpretation is very difficult. Some of these red clays, particularly those derived from the basic igneous rocks, are of homogeneous texture. Others show a distinctly laminated character. This lamination was for a time thought to be peculiar to the residuum of the substructure of the Culebra clays, but I am unable to formulate a definite conclusion on this subject. The residuals of the river deposits and of the Monkey Hill Tertiaries all weather into similar looking red clays. Even on the Pacific slope, in

the low base level swamps which indent the valleys of the Rio Grande and border the coast of Panama, the residual clays present the same laminated structure. The laminated red clays can be continuously traced from Culebra as far north as Gorgona, everywhere overlying the massive igneous rocks and some of the igneous boulder formations, and I am inclined to think that some of them, with the exception of the swamp levels, are the residuum of the Tertiary sediments.

PART III.

The Pacific Coast from Panama to Punta Arenas, Costa Rica.

Leaving the island of Naos in the Bay of Panama at night, we reached Cape Mala, the outer point of the Gulf, the next morning. After turning the point of the cape, we sail close alongside the straight shore line between Cape Mala and Mariato Point. Here the Pacific breaks abruptly against what is perhaps the widest portion of the Isthmian mainland. The accompanying sketches (Figs. 17–21) will convey an idea of the general topography of this region. From the steamer's deck nearly all the details of the coast topography can be seen. The interior consists of an east and west line of high conical summits rising to a height of at least 2,000 feet, between which and the coast were successively lower hills. The higher summits are more elevated in general than along the line of the Panama Railway section, but they present the same type of configuration.

At the water's edge the coast shows in many places low vertical bluffs from 20 to 100 feet, which are being attacked by the washing of the waves. Sailing parallel to these bluffs and within a half mile of them we could make out the same familiar red clay so universal in the Isthmian region. Sometimes there were beds which were apparently stratified and not of igneous origin. Again the massive igneous rocks would predominate; they are especially conspicuous as we approach the western end of this headland. At one point we could see black stratified rocks, resembling shaley clay or green sandy marl, with strong dips to the northward.

The accompanying sketch of Mariato Point (Fig. 17) gives most of the characteristic elements of this coast. It shows the wave-cut bluffs rising from the water's level, and the higher peneplain surmounting the bluffs and backing against the higher mountainous interior. The islets

projecting away from the point show the same topographic forms as the mainland, and it is clear that they have been severed from it.

From Mariato Point to Matapalo Head, the latter marking the extremity of the peninsula which encloses the Gulf of Dulce, the arrangement and topography of the numerous islets present additional evidence that in this region an immense stretch of the mainland has been eroded by the Pacific; the islands remain as monumental evidence of this decay, being geologically and topographically identical with the mainland.

Our steamer strikes out due west from Mariato Point to Jicarita Island, the southernmost of the Coiba group.

A glance at Jicaron and Jicarita islands shows that they have clearly once been connected with each other, and more remotely with the mainland. They have the same identical coast characteristics as the

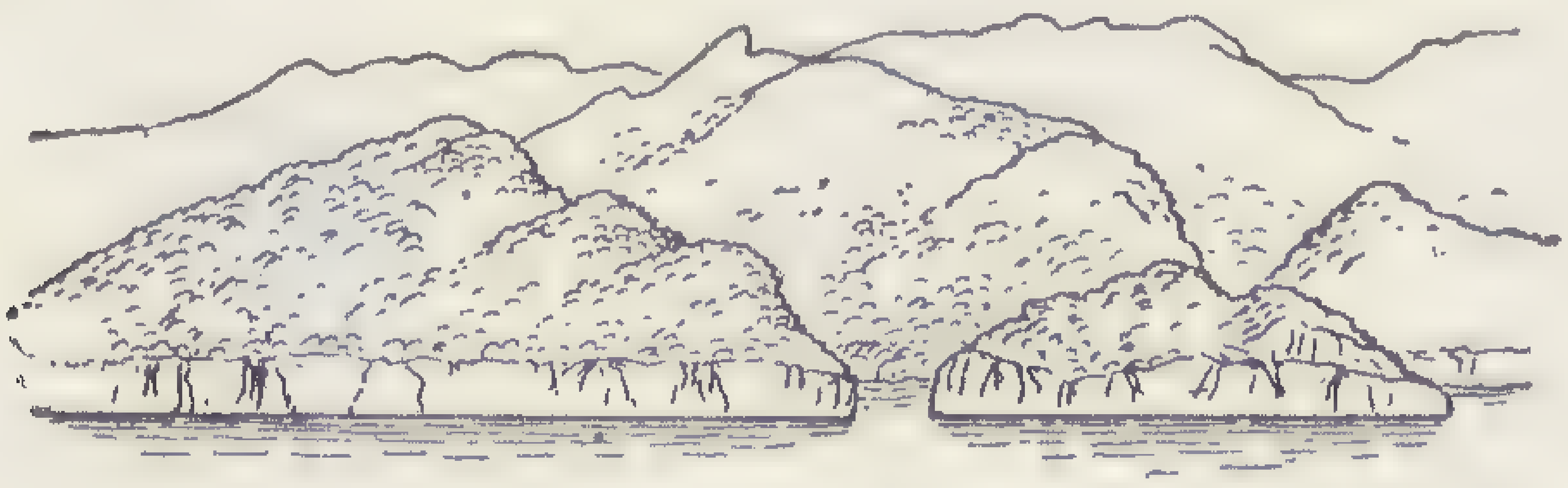

FIGURE 17. Coast Topography between Mariato Point and Moro Puercos.

islands of Panama Bay and Mariato Point, and likewise above this they show the older peneplain topography. Jicaron is dominated by a three-cusped mountain in its centre, identical in topographic aspect with many of the summits of the Isthmian mainland. A small remnantal rock stands a few feet from the main shore, rising to the height of the wave-cut terraces, and apparently having been but recently separated by wave action. Above the wave-cut coast bluff of the larger islands there is a rapid slope of erosion ascending to the peneplain level. The rock of these islands appears to be a white andesitic looking material.

We get a distant view of the large island of Coiba sufficient to show that it is of the same type of denuded mainland topography which we have described. Here can clearly be seen the wave-cut cliffs, the Panama peneplain and low summits similar to those of the Isthmian topography.

From the passage between Jicarita and Jicaron the vessel strikes for Cape Matapalo, and land is temporarily lost to view. The steamer did not enter the Gulf of Dulce, but kept close to the shore line of the bordering peninsula. The same wave-washed cliff lines are visible off Cape Matapalo, the coast and the stretch of low peneplain extending inland from it to the mountainous masses of the interior.

From Matapalo westward toward Burica Point we see the first extensive stretch of swamp level along this coast. This, together with

FIGURE 18. Salsipuedes Point.

other topographic features of the region, is well illustrated upon the hydrographic chart of the Gulf of Dulce. This swamp level is identical in character with the Isthmian features, and from its aspect I could consider it to be a littoral sea margin of recent elevation. Back of this swamp with its bordering lagoon are the high hills of the Dulce peninsula, rising to 1,600 feet in height.

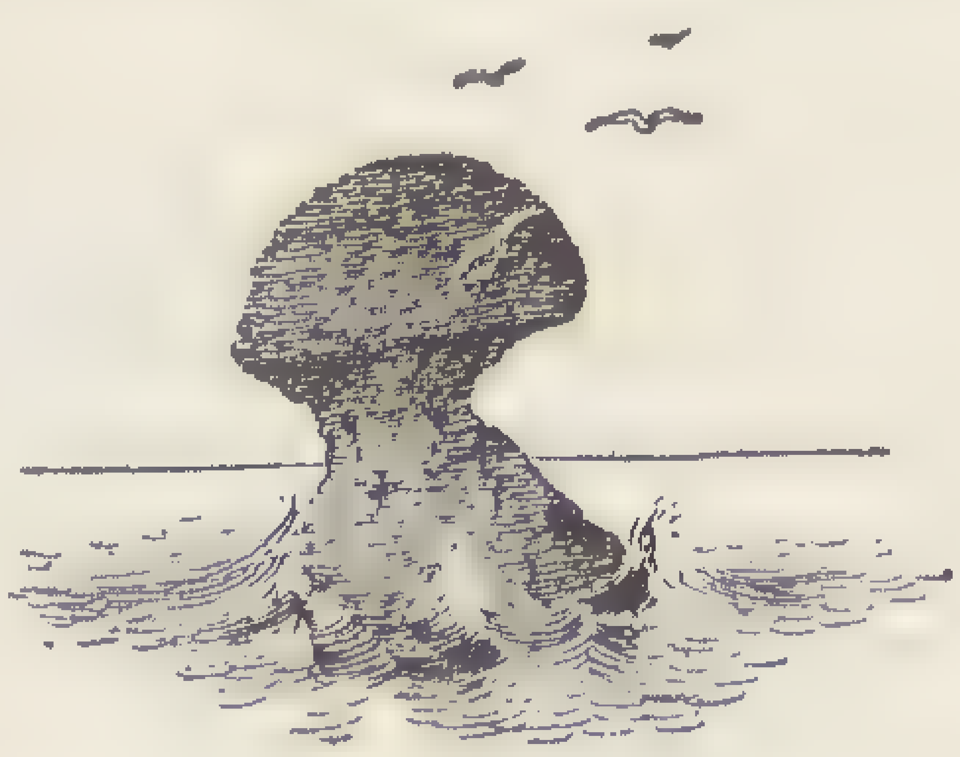

FIGURE 19. Cucovada Rock, near Peninsula of Salsipuedes.

Subsequently we passed Point Salsipuedes, with its small outlying rocky islets as if they had been recently separated from the mainland. One of these, known as Cucovada Rock, has a mushroom form, the waves having eroded its basal portion so that only a small pedestal is preserved as a central support to the overhanging ledges of the summit, which is of the Panama peneplain level. Similar outlying islands are seen off Lorena Point. Just before reaching the latter we pass many miles of vertical wave-cut bluffs, the sea apparently encroaching directly on the mountain country, without the intervention of the lower levels. At one point a beautiful waterfall can be seen dropping from the summit of the bluff into the sea.

FIGURE 20. Waterfall into Pacific Ocean near Lorena Point.

Lying to the northwest of Lorena Point is the island of Cano, which rises from a submerged platform extending many miles westward out into the Pacific. This island, as will be seen by the accompanying sketch, consists of a remnant of the old coastal peneplain. It, too, has many outlying remnantal rocks. This island has undoubtedly been severed by marine erosion from the Lorena mainland.

FIGURE 21. Cano Island, off Coast of Salsipuedes.

From Cano Island no land is seen until we reach Judas Point, marking the entrance to the Gulf of Nicoya. The background consists of the rugged mountains of the Sierra Candella. A high summit, called an extinct volcano upon the hydrographic chart, rises to a height of nearly 8,000 feet, while others near by in the background are nearly 12,000 feet. These are apparently portions of the great peaks which constitute the summit region of the province of Talamanca, the southward continuation of the Costa Rican volcanic plateau. Judas Point shows the same features of outlying rocky islets, coastal swamp, wave-cut cliffs, and the Panama peneplain, as we have observed all the way from Panama to this point, thus showing the continuity in this region of the Pacific of the same geomorphic features.

No student of topography can make this trip along the Pacific coast from Panama to Punta Arenas without being impressed by the fact that large areas now covered by the waters of the Pacific were once occupied by an extensive mainland, which has been so destroyed by the erosion of the Pacific that it is now represented only by the few remaining islands and peninsulas we have mentioned. A line connecting the outer point of the peninsulas of Nicoya and Salsipuedes with the outer capes of the Gulf of Panama will enclose an area of the Pacific Ocean which has certainly been land at no remote geologic period.

The essential features of the Isthmian section can be traced along the whole coast of the mainland: the continental mass of eroded pointed mountains, bordered by the Panama peneplain, or erosion level,

and the coast swamp level, — the two last mentioned features indicating two successive continental uplifts without serious deformation.

The outlying islands are not coralline, like many of the Caribbean, not a single evidence of either growing or elevated reef structure having been seen. Neither are they volcanic cones or craters which grew up singly from the ocean, but they are composed of the same masses of ancient, greatly eroded basic rocks as the mainland, and they have evidently participated in the identical vicissitudes of uplift and subsidence. Comparing them from shipboard with the adjacent mainland, one cannot escape the conclusion that they were once continuous with it, or that they were once parts of each other.

PART IV.

A Continental Section across Costa Rica in the Longitude of San José, from Punta Arenas to Port Limon.

In order to obtain further light upon the structure of the Isthmus, I made an overland section across Costa Rica from Punta Arenas, a Pacific port on the Gulf of Nicoya, to Port Limon, on the waters of the Caribbean.

The section, or rather portions of the section, I will describe through Costa Rica has been the subject of several publications,[1] but it is one of such magnitude and grandeur, that much still remains to be recorded concerning it, and I shall point out several new and important elements which have hitherto been overlooked.

It was also my fortune to fall in with Mr. Ahe Sjögren while in San José, a young mining engineer of unusual acumen, who had been for two years industriously studying the region, and who had spent much of the time upon the peninsula of Nicoya. He accompanied me from San José to Cartago, and together we ascended the volcano of Irazu, and made the journey from thence to Port Limon. I am indebted to him for the excellent section of the disturbed Tertiaries of the Atlantic slope, from Las Animas to Las Lomas, which is printed herewith

[1] One of these sections, by George Attwood, Esq., is an admirable sketch of the principal phenomena of the section as far east as the volcano of Turialba, which marks the border of the Atlantic declivity. He does not touch upon the latter subject, however. On the Geology of a Part of Costa Rica, by George Attwood, Esq., F.G.S., F.C.S., etc. With an Appendix by W. H. Huddleston, Esq., etc. Quarterly Journal Geol. Soc. London, 1882, pp. 328–340.

(Plate VI. Fig. 2), and which he made at my request immediately after my departure from Port Limon.

Notwithstanding the contributions above mentioned I found several new facts of interest concerning the geological history of this region, among them the discovery of Cretaceous limestone near the summit of the divide, the existence of granites on the eastern slope, and the tracing of the details of the topographic evolution, — a subject to which no attention had apparently previously been paid.

The chief geologic features of the section across Costa Rica may be divided into seven conspicuous categories, as follows: —

1. The foundation rocks of ancient quartzites, serpentine, jadeite, and granite, the latter rarely exposed, owing to concealment by the later formations. These rocks are of unknown age, but probably Pre-Cretaceous.

2. Old limestones of supposedly Cretaceous age, outcropping at only one small locality in the valley of San José over 5,000 feet above the sea.

3. The older basic igneous rocks, — mostly augite andesites and other basic igneous rocks possibly of late Miocene and certainly of Eocene Tertiary age, similar to those constituting the Isthmus of Panama. These largely conceal most of the older formations, and are themselves in turn largely buried beneath the volcanic accumulations of later Tertiary and present time.

4. The marine Tertiary sediments of the Caribbean side, from Eocene to Pliocene age inclusive, which have largely been disturbed, elevated, and broken through by igneous protrusions.

5. The line of great volcanoes surmounting the crests of the Sierras, and their accompanying igneous rocks.

6. The Pleistocene or recent sediments of the coasts.

7. The bolsons, base levelled plains, benches, cañons, and other topographic features.

The accompanying profile (Plate IV. Fig. 1, Plate V. Fig. 2, Plate VI. Fig. 2) of Costa Rica shows the general character of the section which I traversed, from ocean to ocean, and I shall not weary the reader with more detail than necessary briefly to describe the chief features. The profile is divisible into four well marked subsections. First, the peninsula of Nicoya, separated by the Gulf of Dulce from the mainland; second, the Pacific seaboard from Punta Arenas to the summit of the Aguacate range of volcanic hills; third, the central volcanic plateau, extending from the Aguacate range to the eastern slope of Turialba;

fourth, the Atlantic declivity, extending from the summit of Turialba to the waters of the Caribbean near Port Limon, a distance of only 40 miles, in which distance there is a rapid descent of nearly 12,000 feet. Bordering this is a narrow coastal plain.

The Peninsula of Nicoya. — This peninsula is dominated by low mountains which seem in direct strike with those of the Salsipuedes Peninsula and Coiba Island, but the geologic problems of this fragmentary continental section will not be completely solved until its structure is studied in detail. In the appendices of this report will be found a few supplementary remarks on this interesting region from Mr. Sjögren.

As viewed from the sea, the peninsula of Nicoya has the same character of hilly topography as the adjacent mainland. Its rocks are largely made up of silicates, quartzites in which greenish colors prevail, and the ancient Isthmian eruptives. I studied the collection of gravels brought down from this peninsula into the Bay of Dulce. They all indicate that this is the prevalent hard rock of the region. Gabb states that lignite-bearing clays are reported from the peninsula, but we have not a single line of evidence from any observer concerning its geologic position or relations.

The green quartzites are apparently the remnant of the oldest rocks exposed in Costa Rica, unless it be the Siquieres granite. On the eastern declivity, where the rapid fall of the Revantazon cuts down within a short distance nearly 4,000 feet, and below, making the lowest exposures, these rocks are again exposed and brought down as gravel, showing that they must underlie the vast accumulation above them.

The San Mateo Peneplain. — The region between Punta Arenas and Aguacate consists almost exclusively of the older basic igneous rocks and their débris. These rocks, as has previously been shown by Attwood and Huddleston,[1] are nearly all augite andesites. The country from the coast to the foot of the Aguacate range is a typical peneplain which has been elevated to an average height of about 800 feet. This has been cut into numerous vertical chasms by the newer drainage which has developed upon it.

No sedimentary strata or beds of massive igneous rocks of any kind are seen along this region. The sole geologic formation consists of an

[1] On the Geology of a Part of Costa Rica, by George Attwood, Esq.; and Report on some Rock Specimens collected by George Attwood, Esq., by W. H. Huddleston.

immense thickness of red clay in which are more or less sparsely embedded irregular boulders of basic igneous material. This is the so called "boulder clay" (see Plates XVI. and XVII.) of Tropical America, and it is by far the most widely developed and conspicuous geologic feature of the region. Vertical cuts of a hundred feet or more were frequently exposed, but they all reveal the same monotonous red clay and scattered boulders, and there can be no doubt but that the entire formation of this bench is composed of the older igneous débris which has rolled down from the former heights of the interior country. The streams cut down below the summits of this bench, but nowhere did I observe a massive exposure of the original igneous rocks west of the Aguacate range. These clays, at least along this portion of the western coast, are clearly older in age and underlie the mass of material composing the greater heights consisting of different species of more recent volcanic ejecta, which will be seen as we proceed eastward from San Mateo to Atenas across the Aguacate range. These boulder clays are the same which Belt mentions in his "Journeys through Nicaragua," and to which he attributed a glacial origin.[1] Mr. Sjögren and myself frequently discussed the nature of these clays as we encountered them at various intervals almost to the Atlantic seaboard, and we could not convert ourselves to the glacial explanation, or consider the clays as being other than ancient oxidized volcanic débris. Mr. Sjögren stated he had searched in vain throughout the whole region, from Lake Nicaragua southward, for any evidence of glaciation such as striæ, morainic deposits, etc., and that in nearly every locality the evidence was clear that the clays were decomposed volcanic ejecta.

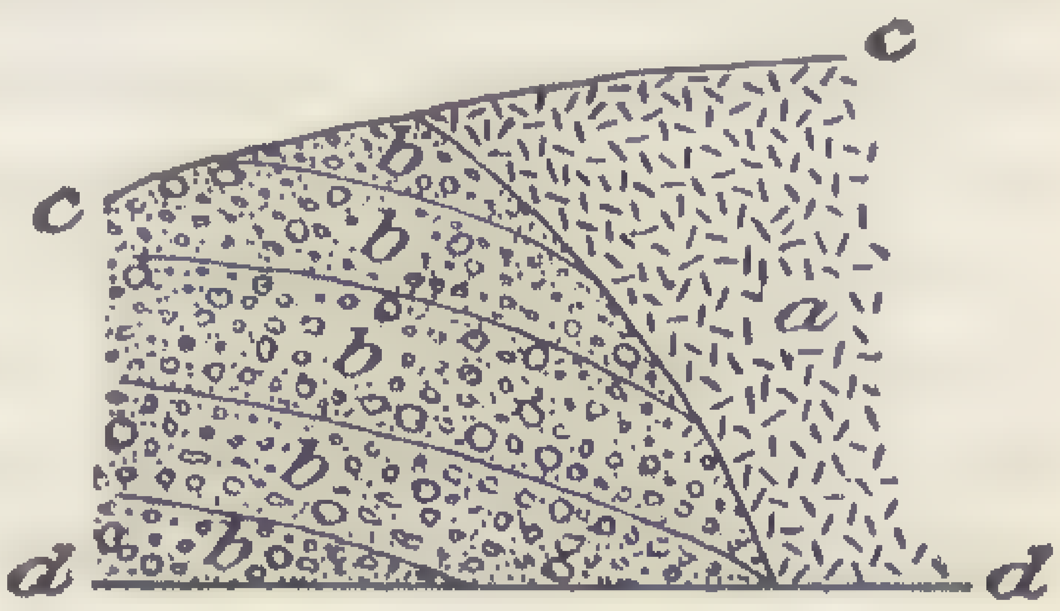

FIGURE 22. Section on Side of Road ascending Rio Grande, Costa Rica, opposite the Garita (Gabb).

The volcanic heights of Costa Rica are chiefly built up by successive accumulations of débris from the volcanic vents which have so long been seeking successively higher and higher outlets through their own débris. The ejected material, greatly aided by the tremendous rainfall of the region, has found its way by gravity down the steeper slopes. The boulders represent the survival of the hardest in this process, while

[1] See "The Naturalist in Nicaragua," by Thomas Belt, London, 1888, pp. 247, 260, 291.

the clays are the oxidized residuum of the more pulverulent ejecta. The older layers of this débris having been buried longest beneath the successively newer and newer accumulations, are much more oxidized and decayed.

Many writers speak of a fine dust which constantly overwhelms the traveller in this region, as volcanic ash. Except upon the higher summits of Irazu, as is probably the case with the other great volcanoes, I found no undoubted deposits of unindurated or unaltered volcanic ash. It is true, however, that while the red clays may originally have been largely made up of volcanic cinder, they have entirely lost their original character as such, and the dust is only the wind dried and blown detritus of the present residual clays.

The Aguacate range of mountains is a lower line of volcanic summits, not exceeding 5,000 feet in height, bordering the western side of the main volcanic plateau which constitutes the heart of Costa Rica. From our ship in the Gulf of Dulce and while crossing the Pacific slope we could see the barren volcanic rocks of these hills, and many summits which resembled small parasitic craters growing from the older range. Between San Mateo and Alajuela the highway climbs over this range; ascending the pass over these mountains from the interior margin of the San Mateo peneplain, which here had altitudes according to my rather uncertain aneroid barometer of 920 feet to a height of 3,000 feet, the road constantly follows a series of zigzag courses overhanging steep bluffs. Numerous exposures made by the workmen in constructing this road everywhere revealed white and green rotting tuffs of a newer aspect than the boulder clays of the lower slopes, with occasional boulders of more massive rock. This decomposed stuff extends to the very summit of the range, and there is hardly an outcrop along this most favorable section of a massive rock *in situ.* According to Professor Wolff's determinations the later rocks from Aguacate summit consist of a decomposed trachyte lava, showing fluidal (pyroclastic) structure, with some fragments of similar lava. The whole mountain, in fact, is a mass of volcanic ejecta. I could not find along the road through the pass any other material than the scoriaceous tuffs, but, as Attwood [1] has previously noted, and as I have myself verified, the older augite andesites underlie the later volcanic ejecta of this range, as is shown in the cañon of the Rio Grande which cuts across its base. (See Fig. 22.)

From the pass at the summit of this range is seen one of the most instructive of geographic panoramas. Looking back from the mountain

[1] *Op. cit.*, p. 134.

toward the Pacific over the course we have just travelled, every detail of the geography is brought out in the clearest relief. The peninsula of Nicoya and Gulf of Dulce and the broad waters of the Pacific can be clearly distinguished, while the really rough surface of the San Mateo peneplain, which we have been crossing since leaving Punta Arenas, spreads out like a level plain below us, the summits upon which we stand having clearly been piled up above it by volcanic ejection.

The Central Volcanic Plateau. — Looking to the eastward, however, the eye beholds an exquisite view of the central volcanic plateau of Costa Rica. This presents a complete and sudden transition from the scenery covered by vegetation which everywhere prevailed since I landed, to an open, timberless mountain and basin topography. The transition is as if one had been suddenly taken from the Isthmian lowlands and deposited into the great bolson valleys of Mexico or those of our own Cordilleran region. As far as I could see, the superb summits of the Costa Rican volcanoes form a background, Poas (altitude 8,700 feet) [Plate XIX.], Barba (altitude 9,000 feet), Irazu (altitude 11,350 feet), and Turialba (altitude 11,300 feet), while in the foreground between them and our point of view, at an average altitude of 5,000 feet above the sea, lie the great fertile upland basin valleys of Costa Rica. The landscape changes in color from the deep green of the coastal vegetation to the grays and browns of the higher mountain scenery of western America. The mountains as a whole have not the aspect of symmetrical cinder-cones, however, but collectively they constitute a long series of high, serrated masses with slopes deeply scored by erosion, very much resembling our own Rocky Mountains. These masses are surmounted here and there by true cinder cones, which in themselves form but a small proportion of the entire mass. I had anticipated seeing the volcanoes with great interest, but had not expected to find the magnificent types of the ancient bolson (basin) topography spread out at my feet like those which are such a familiar sight in the Cordilleran regions of Mexico and the United States. In this topography will perhaps yet be found important evidence concerning the evolution of the region, and a key to the age of the great mass of the mountains of which the present craters are only the surmounting finials.

Upon the maps and profile three of these basins are indicated. These may be called the Alajuela, San José, and Cartago bolsons, respectively. I regret that it was impossible to map them out accurately, for to my mind they are by far the most interesting and important feature in the Costa Rican topography, and upon the slopes in the surrounding

country there can be seen evidences of terraces which, if properly studied, could be interpreted into an interesting geologic history. The beautiful suburb of San José, known as the Savanna, is a small flat area composed of lacustral alluvial soil, and so level that it looks as if the waters had only been recently withdrawn from it. In no instance is there any body of water now retained in the lower levels of these ancient lake

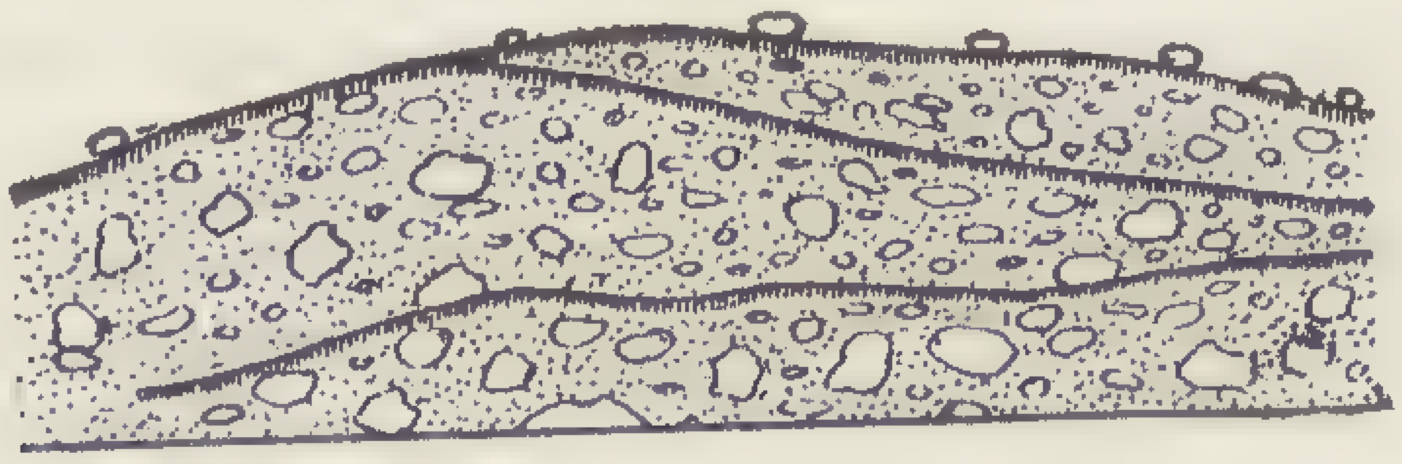

FIGURE 23. Section of Boulder Clays, Flank of Irazu Summit, between San José and Cartago (Gabb).

beds, for the modern drainage has and is now cutting deep cañons into them far below the last lacustral occupation. These streams reveal in their cañons and gorges the same red clays and igneous boulders so characteristic of the older igneous foundation encountered upon the Pacific coast. In addition there are many outcrops of massive black igneous rocks. The accompanying illustrations give a characteristic picture of the boulder topography of the lowest drainage cuts in the central basin (Plate XIV.).

The San Miguel Beds. — On the south side of the east and west chain of bolson valleys, and standing parallel with and opposite the volcanic heights forming their northern border, there is another large range of mountains running east and west, known as the Sierra Candella. Although there is no mention of limestone formations in Costa Rica, I was informed that the lime used in the city was burned from the stone found in the base of these mountains. I visited the site of the kilns, some three leagues south of San José, near the villages of San Miguel and Desamparado. The road the whole distance ascends about 400 feet above the city through the volcanic tuffs, including some of the later and whiter volcanic rocks that I had not seen elsewhere until we reach the foothills of the mountains. This I found to be composed almost entirely of a massive blue-black Paleozoic looking limestone which was being quarried at several places. The strata were much disturbed, dips being found in many directions, but so concealed by the vegetation that it was impossible to make out any systematic arrangement. The only conspicuous fossils that we could find after much search was a very large

Pecten, resembling some of the Pectinoid forms of the Tertiary. By sawing and polishing a number of specimens of limestone, they were found to be largely composed of the shells of Rudistes and Inoceramus, families characteristic of the Cretaceous period. Innumerable shells of oysters and indeterminate Foraminifera also occur in this limestone. The Rudistes and Inocerami attest the probable Cretaceous age of this limestone, which here occurs 4,500 feet above the ocean. So far as I am aware, this is the only known outcrop of rocks of the Cretaceous period between Guatemala to the northwest and the Sierra Del Marta at the mouth of the Magdalena on the coast of Colombia to the south. Nowhere in the vast Isthmian region have the Cretaceous formations as yet been demonstrated.

The hills composed of these limestones have a different topographic aspect from the others of the region, and apparently constitute a line of low foothills running east and west along the base of the Sierra Candella. I traced them nearly ten miles east of San José. The occurrence of feldspar in this limestone as reported by Professor Wolff is an interesting point, as it attests the existence of igneous rocks in this region previous to the deposition of these rocks in Cretaceous time.

Old Volcanic Rocks of the San José Bolson. — While at San José I made frequent excursions in the surrounding country and collected many specimens from the volcanic boulders constituting the older material of the valley, and exposed where the drainage had cut into it below the Savanna level, or old lacustral floor. According to Professor Wolff's determinations these consist of hornblende porphyrite, or andesite, melaphyre, basalt, glassy hypersthene andesite; altered tuffs with fragments of porphyry; holocrystalline quartz porphyry, or granite porphyry; melaphyre, entastite porphyrite; mica diorite porphyrite. As there is some reason to suppose that the San José bolson is at latest of Pleistocene age, these pre-existing rocks may possibly give additional data concerning the nature of the Tertiary eruptives.

Proceeding eastward from San José toward Cartago the railway runs for a distance in the valley of the San José bolson.

After a few miles the road begins to ascend toward the divide at Los Alto, which separates the San José from the Cartago valley. Between San José and this point the cuts of the railway are through yellow loams or clays which have a striking resemblance to the loess-like deposits of the Northern United States. This clay apparently extended up the mountain sides as far as I could distinguish. As the road reaches an altitude of 4,500 feet the timber ceases and we enter a plain covered

with thick grasses. This grassy plain, however, is succeeded on the higher mountains at an altitude of 7,000 feet by another belt of forest, which will be described later.

From Los Alto (altitude 4,993 feet) a beautiful view is obtained of the Cartago basin, which, like those of the San José and Alajuela, were clearly once extensive lacustral areas, and upon the adjacent sides of the Irazu volcano we can distinguish lines resembling terraced benches. The yellow pulverulent loess-like clay continues to be the chief formation until near Cartago, where erosion has again cut down into the boulder clays and older intrusive igneous rocks.

Along the slopes of Irazu mountain may be seen numerous benches, which, if more fully studied, might prove to represent stages in the ancient lacustral topography of the Cartago basin. At the lower end of the Cartago valley, where the river Reventazon cuts out of it, it can be clearly seen that a great flow of volcanic matter (whether from Irazu or Turialba I cannot say) once dammed back the waters toward Cartago. These basins were no doubt formed by the collection of waters in the irregularities in the surface of the volcanic topography, aided by dams of volcanic rocks.

Ascent of Irazu Volcano. — From Cartago (altitude 4,784 feet) I made, in company with Mr. Sjögren, an ascent of the Irazu volcano, lying to the northward of that city, and attaining an altitude of 11,350 feet. In making this ascent we were able to secure a good idea of the structure of the great accumulation of material composing the mass of this mountain, of which the surmounting crater, large as it is, is only a comparatively small summit feature. In the eastern part of the town of Cartago the drainage cuts down to a massive basic igneous rock. From Cartago to an altitude of about 7,000 feet the numerous cuts in the road exposed nothing but the red clays and their contained boulders of black basic rock.

The "Loess" of Irazu. — Between the altitude of 7,000 feet and 9,500 feet we encountered a peculiar geologic formation which I have not seen before recorded from Costa Rica. The whole slope of the mountain throughout this distance is composed of an exceedingly fine pulverulent yellow dust, which in numerous cuts and bluffs occurs as a compact mass in every way identical in lithologic appearance and behavior with the loess deposits such as I have seen upon the Missouri and Ohio, having even the characteristic vertical facies upon weathering. Not a trace of a pebble or fragment of volcanic rock could we find in this substance, although exposures were numerous. In this

loess-like formation grow the beautiful upland forests of Costa Rica, — a kind of second timber belt separated by a zone of grassy plain from the lower belt of forest extending to sea level.

The specimens I collected of this loess-like material were examined by Mr. H. W. Turner, who says regarding it: —

"The fine brown powder labelled 'Loess of Mt. Irazu, Costa Rica, altitude 7,000 feet,' was first examined microscopically with an objective magnifying 225 times. The numerous mineral particles were seen to be much discolored, and difficult of identification. There were numbers of little rods, perhaps siliceous tests or plant epidermis. In order to clear the powder of the coloring matter some of it was treated with hot dilute acid. After drying, the residue was examined. None of the rod-like tests were seen, and although siliceous plant epidermis or tests would not be destroyed by acid, their absence is easily explained because of their light weight, they being probably all removed in washing with the brown coloring matter. Very many of the mineral particles which compose the residue treated with acid were well rounded, and without doubt had been abraded by being rolled about. Other fragments, however, were angular. The most abundant minerals determined were plagioclase, rhombic pleochroic pyroxene, probably hypersthene, and green augite. The hypersthene occurred as small, more or less nearly idiomorphic prisms, and the augite in more rounded grains and irregular fragments. No hornblende was identified, but, as the amount of the material examined was very small, it does not follow that it was not present. No quartz was certainly detected.

"Two thin sections of compact lava from Costa Rica were examined. They were both of a hornblende-pyroxene-andesite containing both augite and rhombic pyroxene. According to Professor Hill, these specimens represent the prevalent lava of the region. It may therefore be safely asserted that the brown powder is largely of volcanic origin, and probably came from volcanoes emitting lavas of the pyroxene-andesite type, but whether it represents a subaerial deposit, or was formed in a body of water, is not evident."

The Crater of Irazu. — After passing the altitude of 9,000 feet, where my aneroid ceased to be of service, to a point where I estimated that we were at an altitude of about 10,000 feet, the loess begins to be covered by the overlapping of a true cinder which had rolled down from the summit above. The tropical vegetation ceased abruptly with the loess at this point, and from thence to the summit of the crater extends a continuous cinder slope upon which grew only scrub oaks and a species of heather resembling very much the blueberry summits of some of our New England hills.

The crater of Irazu has been often described. It is sufficient to state here that it consists of a vast cinder cone nearly a mile in diam-

eter, the highest rim of which, according to Petier, is 11,350 feet above the sea. Within this older crater are numerous later craterlets. The entire crater occupies but a relatively small portion of the great mountain mass which it caps, and is apparently a later parasitic summit growth upon a much older mass. According to the records of the eruptions of Irazu, the principal material ejected in historic time has been hot water. The ejecta constituting the crater, however, consists principally of scoriaceous cinder, accompanied by occasional boulders of black basic rock; and were it not for these historic statements one could believe from its recent appearance that it had been erupted within the past ten years. Of the great mass of material composing the present crater there are only two occurrences of coherent lavas, and these constitute beds only a few feet in thickness, and were probably ejected at widely differing intervals. One occurs in the southern part of the oldest rim; the other is a stratum exposed by erosion interbedded in the ash of one of the secondary craterlets. Professor Wolff pronounces both of these rocks basalt. A piece of augite andesite was also collected from the crater material.

The crater of Turialba, the easternmost of the volcanoes, is very much like that of Irazu. My photographs of the latter not having been successful, a panoramic view of Turialba is herewith given, which will serve to show the general characters of both these gigantic craters. (Plate XIX.)

The study of the craters throws considerable light upon the origin of the older boulder clays. The outer rim of the mother crater of Irazu stands some 200 feet above the interior floor. While most of this rim is fine scoriaceous ash, there are also many large boulders of black massive igneous rock which were thrown out contemporaneously with the cinder. These boulders may be seen to-day rolling down the steep slopes of the cinder-cone crater, the whole hill being striated by the paths they have made in their descent, while the finer material is constantly sifting down upon the boulders, and filling the interstices between them with their substance. If this débris should be subjected to long continued rainfall and oxidation, to which the older clays have evidently been subjected, the finer cinder would decay into a matrix of red clay, producing a result perfectly identical in appearance with the older boulder clays, and the glacial hypothesis would be unnecessary to explain the origin of the latter.

Descent from the Central Basins to the Caribbean Sea through the Cañon of the Reventazon.

From the city of Cartago to the Caribbean Sea at Port Limon the railway makes a descent of 5,000 feet in less than 100 miles, exhibiting to the observer the topography and geologic structure from the great volcanic summits, nearly 12,000 feet in height, to the sea level. The railway follows great barrancas marking the drainage way of the river Reventazon, leading from the Cartago bolson to the sea. Immediately upon leaving the Cartago valley the road threads the mountain side a thousand feet above the bottom of the river gorge, gradually descending the walls of this cañon until it reaches the river at a point still several hundred feet above sea level. From there on the railway follows the grade of the stream to the coast.

Before reading the following remarks on this subject, the reader should examine the profiles and sections given on Plates VI. and VII. These show the precipitous continental slope from the summit of Turialba, the summit line of the cañon of the Reventazon, and the line of the railway, three datum lines which should be kept distinct. The cañon of the Reventazon (Plate X.) is comparatively a new topographic feature, the elevation of the region being shown in its precipitous character. With a few exceptions, to be mentioned, the great section it exposes is composed almost entirely of the older boulder formation and later volcanic material. A few miles out of Cartago the road continues in the boulder clay. Occasionally the railway cuts have penetrated through the superficial oxidized portion of the clay, revealing a white substructure. Some places show these clays resting unconformably upon a foundation of the massive igneous rocks and tufas.

Beyond Santiago the road tunnels through tongue-like salients projecting out from Irazu and Turialba, composed of more recent volcanic material than has been encountered before, comprising many white and pinkish colored igneous rocks of loose scoriaceous texture. One of these tongues of the later eruptives at Santiago once dammed up the valley into a temporary basin, and the later gorge, cut through it, is clearly distinguishable.

At Las Mesas there are other cuts through the lava, and the river flows through a deep gorge. We now reach, in our descent, the basal portions of the great volcanic platform, the structure and composition of which are well exposed by erosion.

Just before reaching Juanvinas the road cuts through a neck of

ancient, massive, black igneous rock, showing fully 1,000 feet of vertically jointed material. According to Professor Wolff's determination this is olivine free basalt, or augite andesite, which everywhere seems to be the chief species of the older igneous rocks.

Beyond La Gloria the road seems to have passed the culmination of the gorge topography of the Central Mountain masses, and the Atlantic slopes of the mountains projecting from the summit of Turialba are encountered. The summits or combs of these numerous salients are deeply serrated by drainage. At this station more massive igneous rocks are seen beneath the superimposed sheets of ash and lava. The old red clays again set in in the cuts east of this station. At Tucurita (altitude about 3,000 feet) the alpine scenery continues, and the road clings to the cliffs far above the river level.

Disturbed Tertiary Sedimentaries. — A greenish looking flaggy formation is encountered near La Gloria, which, from the train, is very suggestive of disturbed sedimentary rocks. One mile east of the station the massive igneous rocks are again encountered. From Las Animas (altitude 1,830 feet) to Lajunta (altitude 250 feet), a distance of only twenty miles, the road descends through distorted and upturned sedimentary strata of Tertiary age, as shown in the profiles and sections. (Plate VI. Fig. 2.) The igneous rocks protrude in every direction through these sedimentaries, and their débris is scattered over the surface. This portion of the section clearly demonstrates that the Tertiary rocks have been folded and elevated to a height of at least 2,000 feet since their original deposition, and that they have been pierced by numerous igneous protrusions. These Post-Miocene intrusives are quite distinct in specific characters from those of Tertiary age, as will be shown later. This section Mr. Sjögren studied in detail. The details on Plate VII. show how thoroughly he did this work. The paleontologic and petrographic determinations of Drs. Dall and Wolff render this section the most complete we have of any portion of the Tropical American region. At Guallava, the next station east of Las Animas, the Tertiary rocks are of Vicksburg age, — according to Dr. Dall, — and, so far as known, the only rocks of this epoch west of the Mississippi. At Bonilla Cliff they are Upper Oligocene, like the Monkey Hill beds.

Throughout this portion of the journey tremendous formations of rolled boulders also occur, apparently interbedded with the Tertiary sediments, and the whole valley of the river is filled with them. The Tertiary clays are well shown just east of Torito, one mile beyond which point the road and river for the first time emerge out of the gigantic

mountain gorges. Two miles beyond this station massive igneous rocks again appear in the cuts beneath the débris and the immense bluff of rounded boulders, like those at Mata Chin upon the Isthmus of Panama. Near Peralto there is a wide flat valley in the foot-hill scenery, which, from a cutting, is seen to be made up almost entirely of these boulders. Five miles east of Peralto there is a long tunnel through an immense hill of rounded boulder conglomerate. Seven and a half miles east of Peralto the railway reaches the river valley at an altitude of 1,500 feet. The sedimentary Tertiary rocks are seen in the bluffs on the opposite side of the river. At Pascaua another intrusive neck of massive igneous material projects through these Tertiary sedimentaries, which Professor Wolff determined to be Theralite.[1]

We now enter the lower hilly country which lies on the Caribbean slope of the volcanic highlands of Costa Rica. This country topographically resembles the surface of the Isthmus; it shows the same pointed character of the hills, the same deeply eroded valleys, and the same vegetation. One mile east of the station last mentioned, at an altitude of 880 feet, 150 feet of greensand marls very much resembling the Mindi beds of the Isthmian section are exposed in a cut. Two miles to the east the river again cuts sedimentary beds dipping to the eastward.

At Los Lomas, altitude 740 feet, there are great bluffs of Tertiary greensand, the strata of which have a very strong dip of nearly 45 degrees. Massive rocks project through the sedimentaries. The river is still in a cañon 1,000 to 800 feet deep. Just before reaching Lajunta the river cuts through a tuff resembling that of Bujio on the Isthmus. At Lajunta we are apparently out of the mountain passes, but the great bluffs of rounded boulder débris which have rolled down the slopes of the volcanic plateaus for ages seem to cover this lower country.

At Siquieres, altitude 390 feet, 37 miles from Limon, the hills are low, not averaging over 200 feet in height, but the boulder bluffs continue in great profusion.

In Cartago, at the house of Mr. Jones, the station agent, we saw a small specimen of white granite, which he informed me he had found up the Rio Siquieres, and had broken off of an immense boulder which lay in the river at that place. This stream is a small river which drains the eastern foot of the Atlantic escarpment of the Turialba volcano, and there is no reason to doubt that granitic rocks occur at the base of this great concealing mass of igneous material. That such granites have existed beneath the Costa Rican volcanic complex is still further attested

[1] See American Journal of Science, Vol. I. p. 291. 1896.

by Professor Wolff's determination of granitic débris in the Tertiary sediments. (See his Report on Specimens, Appendix.) At Pacaurito the road is well in the lower country, but the whole formation still continues to be boulder débris. At Madre de Dios, altitude 340 feet, a little stream flows over a bed of rounded igneous pebbles.

Two miles east of Madre de Dios the foot of the volcanic plateau is passed and we enter an entirely different region. Numerous small flat-topped hills appear, identical in topographic aspect and composition with the Monkey Hill level seen at Colon, surrounded on all sides by a similar swamp as that seen upon the Isthmus. This topography continues to Salsipuedes. From Salsipuedes to Limon, 27 miles distant, the road follows a typical coastal swamp similar to those seen on the Isthmus of Panama and identical in geological character. There is observed occasionally a low remnantal hill of the Monkey Hill level.

The geology in the vicinity of Port Limon is most interesting. There are a few peculiar hills standing about 40 feet above the adjacent

FIGURE 24. Detailed Section at Port Limon, Costa Rica.

swamp level. These hills are "monadnocks," or remnants of an extensive higher level which has been destroyed by base levelling around them. They are seen back of the town and on the outlying Grape Key. They are composed of unconsolidated sands and clays, the stratification of which is greatly crossbedded. These beds contain fossils which Gabb has referred to the Pleistocene or recent. The fringing coral reefs are later and unconformable with these beds. Back of the town, in the railway cuts, this sandy formation rests upon lower lying beds consisting of clays containing great numbers of fossils and reef-making corals. The numerous fossils collected by the writer from this bed, referred to Dr. Dall, were pronounced to be of Pliocene age. These are the type localities of the many Pliocene fossils which have been described by Mr. Gabb from Costa Rica.[1]

The arenaceous formation clearly rests upon these older beds, and is of an entirely different lithologic character. The corals from the supposed Pliocene bed were kindly determined for me by Mr. T. Wayland

[1] Jour. Acad. Nat. Sci. Phila., 2d ser , Vol. VIII. No. 4, p. 349.

Vaughan, and are enumerated in his report appended herewith. They are all common reef building species of the Caribbean region.

Comparison of the Panama and Costa Rica Profiles.

We have now presented two complete continental sections across contrasting portions of the greater Isthmian region. From Mr. Gabb's unpublished paper[1] on the Province of Talamanca we give an additional section of the Caribbean slope intermediate between Panama and San José. The relations of the three sections are also clearly brought out in the geological sections and profiles on Plate VI.

The first and most striking contrast between the Panama and Costa Rican sections is the different topographic aspect. The Panama section is across an old land now nearly graded to the sea, where vulcanism has been quiescent since Tertiary time. The Costa Rican section presents us a view of an ever growing land where the volcanoes have continued to pile their débris from Cretaceous time to the present, suggesting perhaps that on the Pacific side of the continent there has been a compensating disappearance of vast lands by the sinking down of areas from which this material has been extruded.

In addition to the history of Tertiary sedimentation and vulcanism, and the successive epochs of base levelling, the Costa Rican section gives several interesting contributions to help round out the Central American history. The presence of Cretaceous rocks, not found in the Isthmian section gives us a view farther back into geologic history. The great basin valley of the central plateau shows that at least as far back in time as the Pleistocene there was extensive land with the diverse topography of to-day. The marine Tertiary and later sediments of the Caribbean coast of Costa Rica likewise both verify and amplify the records of the Panama section. The presence of marine Pliocene sediments resting unconformably against the folded older Tertiary rocks enables us to fix more definitely the time of the late Miocene orogenic revolution.

In this section we have the orogenic (fold-up) mountains of Cretaceous and Tertiary strata, the piled up ejecta of the volcanic cones, the epeirogenic (lifted-up) coast benches, and the coral reefs of the Atlantic coast. The benches and base levelled plains of the Costa Rican coast record epeirogenic movements of late geologic time in harmony with those of the Panama coast.

The general conclusions to be drawn from these continental sections may be tabulated as follows.

[1] In the library of the United States Geological Survey.

			Marine Sedimentation.	Vulcanism.			
				Panama Section.	Costa Rica Section.		
Cenozoic.	Pleistocene and Recent.	Recent or late Pleistocene.	Marginal reefs of Caribbean Coast.	No evidence of Post-Miocene Vulcanism.	Vulcanism more or less continuous to present epoch.	Quartz trachyte; volcanic ash; porphyrite basalts of crater flows.	Fringing Coral Reefs of Limon, Colon, etc. May have commenced in Pleistocene or even Pliocene epoch. Slight epeirogenic uplift of Isthmian region; restoring drowned lands in part; but not in entirety. Deposition of fringe of Marine Pleistocene sediments. Subsidence, resulting in drowning of mouths of old river valleys and of Panama Bay.
		Pleistocene.	Playas deposits at Panama. Swamp levels deposits of Caribbean Coast. Islands of Boco del Torro (Gabb).				
Tertiary.	Pliocene.		Limon (Moen) beds of Costa Rican Coast.			Theralite, Trachyte Andesite, Hornblende and Pyroxene Andesites. Pyroclastic Trachytic lavas.	Epoch of active and extensive erosion, accompanied by base levelling of the newly elevated land, and the cutting out of the swamp level bights of ancestral valleys of present drainage.
	Miocene.	Miocene (Upper Miocene of older usage).	Missing in Isthmian Section.	Probable time of "Syenitic" intrusions of San Blas and Talamanca.		Granitoid and Syenitic porphyrites probably intruded here.	Tremendous orogenic movements whereby the land was greatly elevated, and configuration of the Caribbean region rearranged.
	Oligocene	Chipola. Vicksburg.	Monkey Hill Beds of Colon; Bonilla Beds of Costa Rica. Guallava Beds of Costa Rica.	Apparent termination of period of basic eruptives in Isthmian Section.			Littoral of the Caribbean Sea extended inland of its present margin, against the older continental land, then covered as now by dense vegetation.
	Eocene.	Claiborne-Tejon. Older Eocene.	Mindi Hill Beds. Gatun (Vamos á Vamos) and probably Chipoango localities of Maack. [1] Foraminiferal Beds of Bujio. [1] Empire Limestone. Culebra clays, and probably much of the lower portion of the Tertiary sediments of Costa Rica.	Active vulcanism. Augite andesites and porphyrites, interstratified with other sediments; also hornblendic andesites and porphyrites.		Augite andesites of Aguacate region.	A shallow passage or passages between the two oceans existed somewhere in Tropical America during this epoch.
Pre-Tertiary.		Cretaceous and Unknown.	Panama Formation (including stratified rhyolitic tuffs of Panama, Miraflores, Barbacoas, and San Pablo). Cretaceous limestones of Costa Rica (San Miguel Formation).	Rhyolites of Panama Formation. ? Unlocated granites brought down by floods of Chagres.		Granites of Siquieres and unknown localities, the débris of which is found in the Tertiary sediments of Costa Rica.	An extensive land area probably existed towards the present Pacific side of the continents during these epochs.

[1] These beds may be identical, and possibly later than the Mindi Hill Beds.

Coal in the Isthmian Tertiary. — The older Tertiary sediments of the Isthmian region are characterized by lignite. The presence of these coals in extensive beds is strong evidence of the close proximity of large land areas during the epoch of their deposition.

While at Colon, Colonel Rives, Superintendent of the Railway, informed me of several coal deposits to the north of the road, especially one of unusual interest on the Rio Indios, a confluent of the Chagres, rising along the divide north of the town of Chorera. Commander Lull's Report[1] gives all the known geological information concerning these localities.

Still westward on the Isthmian region the coal bearing sandy clays have great development around the Chiriqui Lagoon, where they were studied in the year 1857, by Dr. John Evans. In his report he says: "On microscopic examination of their fragments and of the ashes of the coal when burnt, the structure of cellular plants which formed it is discerned quite distinctly. The fossil plants, leaves, etc., associated with the coal, were endogenous and allied to or identical with those at present growing in the vicinity." Later these shells were studied by Dr. C. T. Jackson,[2] who stated that, judging from the fossils, such as Cardum, Cerethium, Natica, Mytilus, and other shells, this coal belongs to the Upper Eocene Period. They were also studied by Gabb,[3] who referred them to the "Miocene," which is the Oligocene of this paper. The fossil shells are all Eocene or Miocene Tertiary (salt water shells); none older were discovered in the coal formations.

The observations of Gabb in the eastern lying province of Talamanca, and of Sapper in Guatemala and Chiapas, show that these lignites are a marked characteristic of the Tertiary formations of the Caribbean coast westward of Colon. They also continue eastward of Colon around the Colombian coast.

Maack frequently mentions these lignite deposits,[4] and considers them to "belong to the Tertiary formation mentioned above."

From these notes it is seen that coal bearing clays have an extensive distribution over the whole Isthmian region and the Caribbean coast of

[1] A description of the Rio Indios coal mines is given on pages 30–33 of the "Reports of Explorations and Surveys for the Location of Inter-oceanic Ship Canals through the Isthmus of Panama, and by the Valley of the River Napipi, by U. S. Naval Expeditions, 1875, Commander Edward P. Lull, U. S. N., commanding Panama Expedition." Washington, D. C., 1879.

[2] Proc. Bost. Soc. Nat. Hist., Vol. VII. p. 423, 428, 1861.

[3] Proc. Acad. Nat. Sci. Phila., Vol. XII. pp. 567, 1860.

[4] Harper's Magazine, 1873, Vol. XLVII. p. 805.

South America, and while I do not wish to correlate all these formations, it seems very probable that they represent localities of the same general formation, representing the earlier half of the Tertiary period.

American civil engineers familiar with the geography of the Magdalena and the Chagres have assured me that there are extensive deposits of lignitic coals in Northern Colombia which are very similar in occurrence and apparent age to those of the Isthmus.

PART V.

The Union of the Continents, and the Problems of the Straits.

Let us now briefly compare the phenomena encountered along the continental cross sections and such fragmentary knowledge of the Isthmian region as can be obtained from the writings of others with what is known of the geology of the whole Central American region, to ascertain what light can be obtained upon questions of the former existence of oceanic passages or land union between the two great continents of the western hemisphere.

Many naturalists in studying the Pacific and Atlantic faunæ, confronted by problems of geographic distribution, have established hypotheses involving former marine connections across the Isthmus of Panama. Such conclusions can be found in nearly every paper on the geographical distribution of marine animals. In many cases the reasons for such conclusion, made by men prominent in their lines of research, have a substantial foundation. In other instances similar hypotheses have largely been influenced by the narrow and elongate shape of the Isthmus. A glance at a map of Tropical America showing the narrow thread-like Isthmian band connecting the two continents always creates an impression that the seas should have joined there, just as one is inclined to restore old land connections between the Antilles and the mainland, or to reconstruct Antillean continents.

In the absence of geologic data it is easy to suppose that the Isthmus is a new made barrier, and the idea that it may be the remnant of an older decaying land does not at first suggest itself. The presence of a few common or similar species among the many dissimilar forms of the oceanic waters on either side of the barrier leads many to a belief in the recent existence of these passages across the supposedly new made Isthmian barrier.

Résumé of the Geological Composition of the Tropical Mainland.

In order to arrive at any conclusion concerning the correctness of these deductions it is necessary to make a brief review of what is known of the geologic composition of the adjacent Central and South American provinces.

Incompleteness of Exploration. — There are many gaps in our knowledge of the geologic history of the Central American region. Several areas must be thoroughly explored before final conclusions can be made. The west coast from Lower California to the equator has hardly been touched upon by any explorer. We know nothing of the structure, paleontology, or source of sediments in this region. That portion of the northwest corner of South America lying west of the Rio Atrato, between the northern terminus of the Andes and the Pacific, is still *terra incognita.*

The detailed work of Sapper in Guatemala,[1] Chiapas, and Yucatan,[2] the study of the San Salvadorian volcanoes by Dollfuss and Monte Serratt, Gabb's exploration of Costa Rica, the detailed sections herewith presented by the writer, and the explorations of Sievers[3] and Karsten[4] along the Colombian and Venezuelan coasts, are the chief contributions to the geology of the mainlands of the western and southern perimeter of the Caribbean.

Old Granitic Rocks in the Caribbean Region.[5] — From the Rio Grande border of the United States to the end of the Cordilleras in Southern Mexico, known as the great "Abfall" of the plateau, no rocks of positive Archæan or Paleozoic age are exposed, although they have been fre-

1 Grundzuge der Physikalischen Geographie von Guatemala. Von Dr. Carl Sapper. Dr. A. Petermann's Mitteilungen, 1894.

2 Sobre la Geográfica y Física Geologia de la Península de Yucatan. México, 1896.

3 Sievers, Petermann's Mitteilungen, 1896, Bonn, Vol. XLII., Part 6.

4 Karsten, Géologie de l'Ancienne Colombie, Boliviarienne, etc., Berlin, 1886.

5 The reader of all Tropical American literature must bear in mind that many rocks are called granites by writers inexperienced in mineralogy which are not granites at all, but either granulites, syenites, diorites, or light colored igneous rocks having a superficial resemblance to granites. The writer always submits his collection of igneous rocks to mineralogic experts for determination, but it has been the custom of many not to do this, and hence the misuse of the term "granite" as above stated. Many of the light colored false granites belong to classes of Tertiary or Post-Tertiary rocks which the writer has observed from El Paso, Texas, southward to Colombia and in the West Indies, upon which studies of future observers will throw much light.

quently reported and may be present in the Western Sierra Madre. Time and again has the writer visited numerous alleged Archæan localities in this region only to find that they were igneous rocks intrusive into a great sheath of Cretaceous sediments which mantles most of Mexico north of latitude 18°.

Along the 18th parallel in the State of Oaxaca low east and west mountains begin to appear. These are composed of granites and gneisses which, according to Felix and Lenk, are of Archæan age.[1] The general strike of these mountain masses of Oaxaca is east and west, and not northerly, as is the trend of the great North American and Andean Cordilleras. These mountains mark the beginning of a remarkable series of east and west orogenic axes succeeding one another in echelon parallel arrangement across the Central American region.

Between the 15th and 17th parallels, in the State of Chiapas, Mexico, and the Republic of Guatemala, there is another group of east and west trends composed of what are apparently Pre-Paleozoic granites. Fortunately we have very definite information upon the geology of this region, thanks to the recent publications of Dr. Carl Sapper.[2] He clearly shows that in this region granites, talc, and chloritic schists constitute the stocks or massifs of ranges of older Paleozoic rocks, covered by a Pre-Carboniferous limestone, presumably Silurian.

Continuing eastward through Central America, Belt[3] has described in Nicaragua a series of rocks which he refers to the Laurentian formation, consisting of "fundamental gneiss . . . covered by strata of much more recent origin." His descriptions of these rocks, no doubt owing to the difficulties of observation in the country, are somewhat incomplete, and it may prove that the folding of the schists and slates which he describes is the product of a Post-Archæan intrusion of granitoid rocks.

The next outcrop of granitic rocks which may supposedly be Pre-Tertiary or fundamental is in the River Siquieres, on the Atlantic slope of Costa Rica, mentioned in our description of that country. Professor Wolff's determination of the presence of granitic débris in the old Eocene fossiliferous sedimentary rocks of this vicinity is an important point, as it shows that granites, at least older than the Tertiary strata deposited

[1] Beiträge zur Geologie und Paleontologie der Republik Mexico, Stuttgart, 1891–93.

[2] Grundzuge der Physikalischen Geographie. Von Dr. Carl Sapper. Petermann's Mitteilungen, Erganzungsheft No. 113, Gotha, Justus Perthes, 1894.

[3] The Naturalist in Nicaragua, by Thomas Belt, London, 1874, p. 259.

upon them, occurred in Costa Rica. Furthermore, from the presence of feldspar in the Cretaceous near San José, we may go even further and presume the existence of a Pre-Cretaceous basement of igneous rocks in the region of Central Costa Rica.

Proceeding eastward Dr. Evans has reported Archæan "granites and syenites along the Chiriqui region."[1] Dr. Gabb, in his manuscript description of the geology of Talamanca, lying in the same general region but nearer the Panama boundary, also describes "granitic" rocks, but shows that they are thrust up through the Tertiary strata of Miocene age. Granitic and syenitic rocks are reported from many places in that portion of the Isthmus east of Colon constituting the mountainous Cordillera of San Blas, lying adjacent to the east and west Caribbean coast. On a previous page it is shown, however, that many rocks mentioned in this paragraph are not true granites.

I was unable to visit the San Blas mountains, of alleged granitic origin, but from the study by Professor Wolff of large numbers of pebbles brought down from the mountains by the waters of the Chagres, which drains them, it is clear that true granite undoubtedly enters largely into their composition.

The granitic ranges extending through seven degrees of longitude due east and west along the Venezuelan coast, from Puerto Cabello to the northeast end of the island of Trinidad, is a remarkable feature which is singularly harmonious with the east and west trend of the known older granitic axes of the Central American region. These granites are called Archæan by Sievers and others, and are Pre-Tertiary. This chain of older granitic rocks lies almost due east, slightly north of the Cordillera de San Blas.

These occurrences of supposedly older granites in the Central American region, fragmentary as is our knowledge of them, at least indicate that, beneath the mighty heaps of volcanic débris constituting the mass of the region, there is an older basement of granitic rocks of earlier age than the oldest determinable sedimentary rocks of their respective localities, — probably Pre-Paleozoic in Guatemala, Pre-Cretaceous in Costa Rica and Venezuela, and possibly Pre-Tertiary in the San Blas region of the Isthmus.

It is interesting to note that in each of the localities where the trends of these granites are known, — in Oaxaca, Guatemala, and Venezuela, — they occur as the massifs of east and west ranges.

From the foregoing facts we may conclude that, possibly previous

[1] *Op. cit.* (work cited in footnote 1 on p. 237).

to the vast accumulations of more modern igneous and sedimentary rocks of Tertiary and Post-Tertiary age, a foundation of granitic rocks occurring in east and west arrangement existed in the South Isthmian and Central American region, extending in echelon arrangement from the longitude of Trinidad through forty degrees to near that of Acapulco, Mexico, directly across the path of the main continental trends.

The Paleozoic Sedimentaries. — Except a few outcrops in northern Sonora fossiliferous Paleozoic rocks are unknown in the Mexican Plateau region south of the Rio Grande of Texas. The Paleozoic foundation of the Mexican Plateau was completely buried beneath Cretaceous limestone sediments, and since the elevation of the latter above the sea erosion has not yet been sufficient to re-expose them. In fact, between the southern boundary of the United States and the Empire of Brazil I know of but one well defined region of authenticated fossiliferous Paleozoic rocks, and this is in the Republic of Guatemala and the adjacent Mexican border region of Chiapas, where Dr. Carl Sapper[1] has shown the undoubted occurrence of a large series lying above the so called Azui granites. He describes the existence of an extensive system of Pre-Carboniferous rocks, probably Silurian, above which are Carboniferous limestones containing 36 enumerated species of characteristic fossils. Above this is a series of strata between the Carboniferous and the Cretaceous, then undoubted Cretaceous, and finally the Tertiary. This Guatemalan section, including its continuation into Chiapas, is the only one in the whole Central American region where undoubtedly fossiliferous Paleozoic rocks are exposed. All positive evidence of the existence of the Paleozoic rocks elsewhere south of the United States is thoroughly concealed by overlap, — in Mexico by the overlying strata of Mesozoic, and in Central America by the later igneous and Cretaceous and Tertiary rocks.

The Older Mesozoic. — In Tropical America as in the United States, owing to the absence of fossil remains, the old Pre-Jurassic Mesozoic is a problematic formation, and is represented by three small outcrops only. Two of these occur in Mexico. One of them is at Miquehuana in the State of Tamaulipas, as discovered by the writer.[2] In these two localities, not only by occurrence beneath the Jurassic, but by their characteristic composition and red colors, they are analogous to the Red Beds formation of the Western United States. The third locality, or group of localities, is in the State of Guatemala and Chiapas, where Dr.

[1] *Op. cit.* (see footnote 1, p. 239).

[2] American Journal of Science, Vol. XLV. p. 311, 1893.

Carl Sapper[1] has described a system of pudding-stones, sands, and red or yellow clays as the Todos Santos beds.

The physiographic significance of the early Mesozoic Red Beds has never been interpreted, even in the United States, where they are so abundant. In general, however, from the shallow water nature of the sediments, the scarcity of marine life, and the presence of plants, they indicate the coexistence of extensive areas of near-by land. No Jurassic rocks are reported from Central America.

The Cretaceous Strata. — The present area of the Republic of Mexico was mostly beneath the sea in Cretaceous times, but, as we shall show in the subsequent discussion, it is doubtful if the whole of the country was entirely submerged at any one time during this epoch.

Cretaceous sediments and limestones are found in the Republic of Guatemala on the north side of the granitic proto-ranges. As I have shown in this paper, there is one small outcrop in Costa Rica. From Costa Rica westward Cretaceous deposits have not been reported anywhere in the Isthmian region, nor are they apt to occur at the surface until we reach the Andean and Caribbean folds of Northern Colombia and Venezuela. Prof. A. Agassiz has mentioned one Cretaceous species from the Isthmus.[2] They are extensively developed in three distinct provinces of the South American continent: along the Pacific border, near the Caribbean coasts of Colombia and Venezuela, and in Trinidad, and south of the Orinoco in Brazil. Cretaceous rocks also outcrop in the islands of the Greater Antilles, Jamaica, Santo Domingo, and Cuba.

The Cretaceous formations of the Pacific coast of South America lie along the upturned flanks of the Andes. The exact relations and limitations in distribution of its faunas have not been thoroughly established or compared with those of the other South American provinces; but from such figures as have been published of its species, we are inclined to believe that it shows the same great dissimilarity to that of the eastern lying provinces of Brazil as does the Cretaceous of our own North American Pacific coast to that of the Atlantic and Gulf region. The Cretaceous of Colombia and Venezuela east of the Magdalena River, as has been fragmentarily published by Boussingault, d'Orbigny, and Karsten, certainly shows a great dissimilarity in species to that of the strictly Andean province. This is a field, however, which needs exploration by some one familiar with American Cretaceous paleontology. The difference between the Brazilian and Andean Cretaceous is even more striking.

[1] See footnote 1, p. 239. [2] *Loc. cit.*, page 173.

There are several apparently distinct localities and faunas in Brazil which have been called Cretaceous by different authorities. The Cretaceous faunas described by Dr. C. A. White[1] are dissimilar to any other Cretaceous faunas of the continent, and G. D. Harris[2] asserts that they are to all appearances equivalent to the midway stage of the Eocene Tertiary of the Southern Atlantic States.

Hart and Hyatt have published contributions which undoubtedly show the existence of Cretaceous deposits in Eastern South America very closely allied to those of the Texas region.[3]

The Marine Tertiary — The marine Tertiary and Post-Tertiary sediments of the Gulf Caribbean region, as well as of the Atlantic Coastal Plain of the United States, can all be placed in two broad physical categories, to wit, formations composed of organically derived sea débris, and formations composed of land wash.

Formations composed of Sea Débris. — The first class of Tertiary deposits are chalky or brecciate white or whitish limestones, composed of sea débris, derived from the deposition or trituration of skeletal parts of marine organisms, and of calcareous matter from that which the sea water holds in solution.

These chalky or clastic limestones sometimes contain a small proportion of washed clay, and are always of whitish color. The clay has been thoroughly washed by long presence in the sea. An occasional particle of pyrites, supposedly an accompaniment of animal decay, may give by oxidation a faint yellowish or cream colored tinge to the rocks, but the darker browns and reds of the first mentioned category are conspicuously absent. The white limestone formations have been made in the past of bottom life and accumulations, or as can be seen in process of making to-day, by the wave and current broken and triturated shell and coral material, cemented by the lime derived therefrom. This class of lime formation may become, through interstitial alteration, irregularly indurated and partially crystalline, and, through solution, cavernous and porous.

The white limestone formations are found in the Floridian peninsula, but especially abound in the insular areas of Tropical America throughout the Great Antilles, Yucatan, and the Bahamas. It is a singular fact

[1] C. A. White, Contributions to the Paleontology of Brazil, Rio de Janeiro, 1887.

[2] G. D. Harris, Bull. of American Paleontology, No. 4, June 11, 1896.

[3] "Report on the Cretaceous Fossils from Maroim, Province of Sergipe, Brazil, in the Collection of Professor Hartt," Geology and Physical History of Brazil, Hartt, Boston, 1870, p. 392.

that, with the exception of the northern half of the peninsula of Yucatan, which is composed of them, and in Florida, formations of this character are strikingly absent along the immense stretch of the coastal region of the Gulf and Caribbean mainland. These sea derived formations are chiefly of Vicksburg Eocene, Oligocene, Pliocene, and recent origin.

Land Derived Littoral Deposits. — These are essentially composed of thinly bedded land débris, — sands and clays, usually unconsolidated, occurring in numerous thin stratigraphic alternations. The accessory conditions are the accompaniment of much ferruginous material, especially iron in the shape of pyrites; and impure lime derived from solution of fossil shells, and the percolation and redeposition of the same. This lime as it occurs is a secondary product, and is never of chalky texture. It is nearly always more or less arenaceous, argillaceous, and ferruginous. Lignite and leaves and stems of plants also occur often in great abundance. This character of sedimentation is indicative that land existed in close proximity from which the deposits were derived, and near which they have been laid down in a comparatively narrow belt.

The Eocene and Oligocene deposits of the whole of the Atlantic Gulf and Caribbean continental borders are largely of this character. These impure alternating littoral land derived deposits compose nearly all of the lower Tertiary formations bordering the Atlantic side of the North Central and South American continents from New England to the east of the Gulf of Maracaibo, and follow the bordering islands thence to Trinidad. Analogous formations are now being made along the ocean's margin within the limit of coastal sedimentation. *We think that no geologist will deny that the proximity of marginal land accompanied the deposition of formations of this character, and that the existence of this land was as certain as that of the formations themselves.*

With the exception of the doubtful Empire limestone, Tertiary formations of the first mentioned class, sea derived formations do not occur in the Isthmian region.

The Older Tertiary Littoral of the Gulf and Caribbean. — There can be no doubt of the occurrence around the Caribbean perimeter of a continuous fringe of the older Tertiary littoral formations of the second class mentioned from east of the Mississippi to the Gulf of Maracaibo, that these formations are largely of Eocene and Oligocene (older Miocene) age, and that they are genetically related to, continuous with, and the product of the same processes as those formations of the Caribbean side of the Isthmus and Costa Rica described in this paper.

It is unnecessary to review the occurrence of the Tertiary littoral north of the Isthmus of Tehuantepec, nor can we here extensively review the numerous fragmentary observations upon the region between Tehuantepec and Trinidad. The researches of Sapper in Guatemala, Chiapas, and Yucatan, of Gabb in the Costa Rican region, and of Karsten and Sievers in Colombia and Venezuela, are of chief importance, and the essence of their reports is as follows.

Guatemala, Chiapas, and Yucatan. — According to Sapper's recent publications,[1] older Tertiary strata are found in numerous mostly small bands in middle Guatemala. A list of fossil genera occurring in these beds is given. They are suggestive of Eocene and early Oligocene age. Fossil wood and lignite also occur.

Sapper has also shown that the Tertiary formations of Guatemala continue into the northern and middle portions of Chiapas, and in the middle portions of Tabasco.

Until recently the Tertiary formations of Yucatan were supposed to be entirely of this white limestone class, and hence the absolute continuity of the older marginal Eocene and Oligocene littoral was not traceable.

The studies of Sapper, however, have revealed the most important fact, that interior of and beneath the white limestone of Pliocene (and possibly late Miocene) age of Yucatan, the older Tertiary deposits of the impure littoral character are highly developed, thus supplying the last missing link in the chain of evidence testifying to the further continuity of this older littoral around the perimeter of the Gulf. Thus the discoveries of this patient German explorer have added greatly to the Tertiary sequence of the Yucatan province.

Thanks to the studies of Gabb in the province of Talamanca, the southeastern division of Costa Rica, along the Atlantic slope between Port Limon and the Chiriqui Lagoon, we are able to demonstrate the continuity of this land derived series of Tertiary sediments as far west of Colon as Port Limon in Costa Rica, and there can be little doubt, as he stated that he believed, that it continued to underlie the common plain of Costa Rica and Nicaragua along the valley of the San Juan, a region however which neither Gabb nor myself has visited.

The continuation of the Caribbean Tertiary littoral belt eastward from Colon to the mouth of the Atrato may be inferred from the observations of Messrs. Maack, Bowditch, and Carson of the Selfridge Expedition. I am personally satisfied that the formations I have described in the

[1] Physical Geography of Guatemala. Peterman's Mitteilungen, 1896.

Isthmian section are largely developed throughout this region. The formations of the River Tuyra described by Maack,[1] are almost identical in character with that of Vamos á Vamos and lie directly within their line of strike, and are much nearer the Caribbean than the Pacific.

From the mouth of the Atrato eastward to the mouth of the Gulf of Maracaibo, and thence in the parallel fringing islands along the northern shore of South America, the record of continuity seems quite complete. Maack[2] found the formations around Turbo, near the southern end of the east shore of the Gulf of Darien, to consist of clays with coal which he thought to belong to the Tertiary period.

The low chain of hills near Cartagena, according to Hermann Karsten,[3] are composed entirely of Tertiary and Quaternary deposits, and they contain thick agglomerated limestone beds alternating with sands and marls, containing beds of argillaceous sandstone very much like those of the Isthmus of Panama. Karsten also gives many other localities from Cartagena eastward.

Sievers[4] in his recent map of Venezuela, has shown the continuation of the possibly Eocene and "Miocene" formations east of the Gulf of Maracaibo, near the northernmost point of South America, latitude 12°, on the mainland and the peculiar peninsula of Paraguana. East of this peninsula the east and west coast of the northern end of South America drops southward over a degree of latitude, and from Puerto Cabello becomes granitic. The strike of the "Miocene" formations of Paraguana continued eastward is north of the main continental outline, and the formation outcrops in the islands of Curaçoa and Trinidad.

The foregoing observations certainly indicate the existence of a continuous littoral of older Tertiary sediments around the Caribbean side of the Tropical American region, and incidentally a pre-existing land which they bordered. Of course it is impossible, from the lack of paleontologic evidence, to state that these older Tertiary beds are exactly synchronous, but they probably belong to the continuous series of sediments of the Eocene and Oligocene epochs. Sapper shows from their position that they are Pre-Pliocene in Yucatan and Guatemala. Dr. Dall's studies of my own collection, as given in the Appendix, show that they are Eocene and Caribbean Oligocene along the Isthmian and Costa Rican coasts,

[1] Previously cited.

[2] *Op. cit.*, page 160.

[3] Géologie de l'Ancienne Colombie, Boliviarienne, Venezuela, Nouvelle-Grenade et Ecuador, 1886, p. 23.

[4] Petermann's Mitteilungen, 1896, Bonn, Vol. XLII. Part 6, p. 125.

while others have shown that they are Lower Tertiary to the eastward. Collectively this testimony strongly points to the existence of such a littoral in early Tertiary time and to a corresponding land which this littoral bordered.

Pliocene. — The Pliocene formations have not been clearly distinguished in the Tropical American region from the Pleistocene. There is an intermittent fringe of alleged Pliocene deposits around the Caribbean coast unconformably deposited against the older continental mass, which nowhere attains great development except in the northern half of the great peninsula of Yucatan, where it is most extensively developed, occurring as a white limestone formation previously alluded to.

At Port Limon, Costa Rica, the supposed Pliocene, as described by Gabb and seen by the writer, appears as impure clay marls near the sea margin. It is missing in the Isthmian section and sparsely represented, if at all, on the Colombian coast, where it has not been differentiated.

We may infer from the relatively slight area of the marginal development of rocks of this period, and their absence in the elevated or folded regions away from or much above the coast line, that it was just prior to the Pliocene period or during its earlier days that the Caribbean coast line, as a result of the tremendous orogenic processes by which the earlier Tertiary rocks were deformed, practically assumed the shape as we now know it. No sedimentary rocks of Pliocene age have been reported from the Pacific coast of the Central American region. Gabb's studies of the Pliocene of the Costa Rican coast, and Heilprin's of Yucatan, are the only definite determinations of the rocks of this age in the Central American region.[1]

Pleistocene. — The marine Pleistocene rocks of Tropical America are not clearly separable from the Pliocene on the one hand, or the recent formations on the other. Undoubtedly, however, there is a fringe of deposits which can be very safely referred to this epoch which borders more or less intermittently both the Atlantic and Pacific coasts, occurring at or only a few feet above sea level south of the Honduras peninsula.

In Yucatan, according to Heilprin, the Pleistocene has the white limestone facies, and is indistinguishable from the Pliocene. In Costa Rica, at Port Limon, a more sandy formation, which may be Pleistocene, rests upon the underlying Pliocene clays, described by Gabb. These

[1] While reading these proofs another list of Pliocene fossils comes to hand. This, as determined by Dall, and published by Spencer, is from the Caribbean coast of Tehuantepec. See Bull. Geol. Soc. of America, Vol. IX. pp. 24, 25. Rochester, 1897.

sands seen in the hills in the edge of Limon rise to a height of over fifty feet above the sea, and contain casts of marine shells. The Pleistocene of the Isthmus proper is fully detailed elsewhere in this report.

It is an important fact, however, that reef making corals were found by both Gabb and the writer in the "Pliocene" of Port Limon beneath the later sand formations. If the fringing coral reefs of Colon and Limon are Pleistocene in origin, then the time of reef building extends through at least two epochs, for the fringing reefs are also of later origin than those of the alleged Pliocene formation above mentioned.

The non-marine aggradational deposits of the large river valleys of the region, which seem to grade coastward into the marine deposits, are subjects of great interest. Too little is known regarding them, but there is no doubt that the enormous matrices were cut out previous to early Pleistocene time, or at least as far back as the Pliocene. Aggradational deposits of Pleistocene age now fill these valleys inland far up the streamways towards their headwaters. The great swampy valley of the Atrato of this character is nearly 500 miles in length, having perhaps one of the longest tidal reaches in the world.

The statement of Upham,[1] Spencer,[2] and others, that Maack found marine Pleistocene fossils at great heights on the Isthmus is erroneous. Their conclusions were based upon Maack's allegation that Pleistocene marine fossils were found on the divide. The locality given is on the Caribbean side, and the fossils collected have since been shown to be Tertiary.

The great upland lakes of Central America, including the old drained lake beds of Costa Rica and possibly of Panama, most probably date back to the early Pleistocene epoch, but these phenomena indicate land conditions rather than marine. Cope[3] has recently described an extinct bovine (Bos scaphoceros) of undoubted Pleistocene age from these deposits in Nicaragua. The same species, as determined by Mr. F. A. Lucas, has recently been found by me in the Equus beds near Austin, Texas.

Diastrophism and Vulcanism of the Tropical American Mainland.

The building up of land by various processes of elevation, and the levelling of the surface by erosion, afford important data for tracing the

[1] American Geologist, Vol. VI. p. 396.
[2] Bull. Geol. Soc. Am., Vol. VI. p. 125.
[3] Journ. Acad. Nat. Sci. Phila., Vol. IX. p. 487, 1894.

geologic history of this region. By examining the results of these processes we may possibly obtain some light upon the architecture of the Isthmian country, while the paleontologic data will give us the historical facts.

Predominance of East and West Orogenic Trends. — In the introductory chapter of this paper we have outlined the general arrangement of the mountain systems influencing the topography of Tropical America. From the publications of Felix and Lenk upon the southern termination of the Mexican Cordilleras,[1] those of Dr. Carl Sapper on the Guatemala-Chiapas province,[2] of Sievers's map and résumé of the Caribbean coastal region of South America,[3] and of my own,[4] we find a description in widely separated localities of the *prevalent east and west trend of the orogenic systems* of the Great Antilles and the peripheral Caribbean lands, and the demonstration further that in this region there has been an area of late Tertiary mountain making, whereby a new system of mountains has been made directly tangential to that of the prevalent trends of the main North and South American Cordilleras.

Excepting the gigantic eminences piled up by volcanic extrusion, beside which all other surface features seem trivial, this late Tertiary mountain folding is the most conspicuous and far reaching event of all geologic history in Tropical America. Before it, however, other orogenic periods and results are manifest, concerning which we shall endeavor to present what little is known.

Evidence Indicating the Existence of a Pre-Tertiary Orogenic Complex. — The granitic mountains of Oaxaca, Chiapas, and Guatemala, with their laterals of Paleozoic and Mesozoic rocks, apparently belong to one or more orogenic complexes of great antiquity in origin. It is immaterial here whether they are Archæan or not, but they may in part antedate the Tertiary period, and seem to be of Pre-Cretaceous age, and give us a faint insight into the existence of an ancient land in this region. According to Sapper[5] the Archæan foundation along which is arranged the Paleozoic and Pre-Carboniferous complex of strata plainly shows in two chief chains, lying to the north and south of Rio Motagua, while in the southeastern portion of the country they show in the spurs of a third chain. From these foundations stretching through the north are Carboniferous, Cretaceous, and finally the Tertiary strata. Besides, one

1 "Ueber die tektonischen Verhältnisse der Republik Mexico," Berlin, 1892.

2 *Op. cit.*

3 *Op. cit.*

4 National Geographic Magazine, May, 1896.

5 *Op. cit.*

encounters in going southward from the primitive rocks younger and younger eruptive strata. First, a broad stretch of old eruptive rocks, andesite, trachyte, basalt, etc., while the volcanoes, the youngest eruptive formations of the land, rise for the greater part upon a still more southern parallel fissure.

The presence of granitic débris in the rocks of Costa Rica, as shown by Professor Wolff's report upon my collections, clearly testifies that before Tertiary time there was a crystalline foundation against which its littoral sediments were deposited. If we are correct in our assumption that the Panama formation of Rhyolitic tuffs are of Pre-Tertiary age, (and in this we are borne out by the independent observations of Maack and Garella,) we have the proofs that in the Isthmus itself there existed a land nucleus of Pre-Tertiary formations. The true granites brought down from the headwaters of the Chagres may be a further indication of an old Pre-Tertiary basement to the Isthmus, for no rocks identical with these are known in the later intrusives, the so called "granites" of Gabb in Talamanca and of the San Blas range recorded by the Selfridge Expedition as "syenites" being a different class of rocks, which have been intruded through the Tertiary, as will presently be demonstrated.

Karsten, Sievers, and other students of the Venezuelan coast, also assign to a Pre-Tertiary origin the east and west granitic coast of Venezuela. These in their east and west strike are singularly in harmony with the prevalent trends of the Isthmian region.

These fragmentary data are sufficient to indicate that there may have been in Pre-Tertiary time a basement barrier of granitic rocks in an east and west arrangement which outlined the Central American and Isthmian regions, and constituted an ancient buttress against or upon which the later mountain folding has originated.

Epochs of Igneous Activity. — There is every evidence that vulcanism was active in the Central American and Isthmian region in late Cretaceous, or possibly earlier in the vast interval of Pre-Tertiary time, for which we have no paleontologic data to fix a chronology. According to Felix and Lenk,[1] it was at the close of the Cretaceous, near the beginning of the Tertiary, that the gigantic line of Mexican volcanoes had their conception, and the Central American chain of volcanoes was likewise piling up its vast heaps of material during this epoch, while the Andean extrusions may have been in full blast. The rhyolitic tufas of the Panama formation are almost beyond all reasonable doubt of Pre-Tertiary age and show the existence of extensive vulcanism. The pebble

[1] *Op. cit.*

of igneous rock in the basement beds of the Culebra clays, if the latter be of Eocene age, testifies to the presence of basic igneous eruption somewhere near the beginning of the Tertiary, if not prior thereto.

The Tertiary strata of the Chiapas-Guatemala region, according to Sapper, are interbedded with conglomerates of andesite, which must have been extruded prior to the Tertiary period, while in other localities the horizontal Tertiary strata are deposited directly on the andesites.

There is but little doubt, as we have shown in the previous pages of this paper, that during the early Tertiary period itself tremendous vulcanism, probably accompanied by orogenic changes, took place; in fact, no doubt this was the scene of the most cataclysmic revolution of all geologic time and place. We know that the older Tertiary strata elsewhere than along the Isthmian section have been thrust through by igneous intrusion. Theralites, trachytic, hornblendic, pyroxene andesites, augite andesites, porphyries, and basalts have been pushed through these sediments, shattering them by thousands of dikes, sills, and other forms of intrusion.

Theoretically, there is no reason to believe that some of these classes of rocks did not exist before the Tertiary period. We know that at, or just after, the close of the Cretaceous, the igneous rocks which mark the whole American Pacific Cordilleran regions in later times were being protruded in both the Andean, Central American, Mexican, and Rocky Mountain regions, and the data submitted in this report show that this action was taking place in the Isthmian region in early Tertiary time.

The older basic eruptives continue eastward from the Isthmus, appearing in trend with the Isthmus on the peninsulas of Goagira and Paraguana, which guard the mouth of the Gulf of Maracaibo, and in the outlying hills of Aruba, Curaçoa, and Bonaire. They also appear along the 10th parallel, between the 68th and the 66th degrees, in a narrow belt south of Caracas.

The "syenitic" and other deep seated granitoid rocks which have been intruded into the Eocene Tertiary are certainly later in origin than the basic eruptives of the Eocene epoch and older than the later basic rocks of the volcanic plateaux. Their exact status in the Isthmian history is still somewhat involved, but they occupy no uncertain position in the Antillean sequence, as will be shown in our report on Jamaica, where they are directly coincident in age with the great Mid-Tertiary epoch of Antillean mountain making.

We also know that since the Pliocene epoch while the gigantic volcanic cones have continued to bury the surrounding structure with

their débris, that relatively the vulcanism has been more quiescent and the movements have become more of the epeirogenic than of the orogenic character, and the land as a whole has undergone oscillations of upward and downward movements, as recorded in the base levelling described in this paper.

Unfortunately the only bench mark by which the igneous disturbances can be gauged are the older Tertiary and later sediments. From the co-deposition of the volcanic débris in these sediments, we know that the volcanic activity was in progress during their formation. Whether this vulcanism, which we know was in operation at the close of Cretaceous time, with its accompanying disfiguration of topography, was continuous to the present, or alternated with long periods of quiescence, cannot be answered.

The Orogenic Revolution of Later Tertiary Time. — We know that earlier Tertiary sediments laid down in alternating layers have since their deposition been elevated above the sea to great heights by folding on the Caribbean side of the old Isthmian protaxis until they stand 3,000 feet in Guatemala, 5,000 in Talamanca, 300 near Colon, 500 at Cartagena, 9,000 in the Great Antilles, and several hundred feet at various places along the Lesser Antilles.

The older Tertiary strata of Chiapas and Guatemala, according to Sapper, occur entirely on the Atlantic side of the Cordilleran masses. The summits of these masses composed of Paleozoic and granitic material reach an altitude of 12,500 feet. The Cretaceous on their northern flank lies below altitudes of 6,560 feet, while the Tertiary lie below 3,281 feet.

According to Mr. Gabb's researches in Talamanca and my own observations in Costa Rica, the upturned Miocene strata produced by these movements occur at great altitudes of from 3,000 to 5,000 feet.

The admirable geologic maps and profiles of Northern Venezuela by both Sievers and Karsten show the remarkable manner in which the Tertiary rocks have been folded in the east and west mountains extending along the north coast of South America. The almost vertical folded Tertiaries on the peninsula of Paraguana now stand at an altitude of nearly 1,600 feet above sea level. South of Coro, between longitude 69° and 70°, similar folds are seen on the mainland.

In Hayti, Cuba, and Jamaica these plicated Cretaceous and early Tertiary rocks are found at altitudes exceeding 10,300, 8,000, and 7,250 feet respectively above the ocean.

The east and west strike of both the Tertiaries and of the basic igne-

ous rocks along the northernmost coast of South America and in the Great Antilles is directly in harmony with the east and west trend of the same phenomena upon the mainland,[1] and we cannot escape the conclusion that they are the product of the same great orogenic revolution, the age of which was Mid-Tertiary, for rocks of early and late Eocene age everywhere as exposed along the Caribbean coast, and in the Great Antilles, are folded by these mountain making processes, while the Pliocene and Pleistocene are more horizontally laid down against the seaward margin of the mountain masses.

There is a remarkable suggestiveness in the age, character, and trend of these late Tertiary movements with those of the Pacific coast of North America, especially of California and Lower Californian regions. An imaginative mind could easily draw a long sweeping curve along the Pacific coasts of Oregon, California, Lower California, and Mexico, across the continent in Central America and the Antilles, and state that it represented the trend of the great orogenic revolution of the Tertiary time, — a revolution which perhaps produced the greatest known modification of Central American and Antillean topography, and largely established the present shapes of the land areas.

The Epeirogenic Movements of Post-Miocene Time. — We have described in detail the character of the swamp lands in the vicinity of Colon, composed of littoral débris of the ocean, showing that they represent elevation of marginal sea deposits which had been deposited against a greatly eroded pre-existing land. We have shown the existence of the same phenomena upon the Pacific slope of Panama, though of a less marked extent. From the wide distribution of this phenomenon I am inclined to believe that the whole region has undergone uniform elevations in comparatively recent (Post-Pleistocene) time, whereby the shallow margins of the sea have been elevated into low lying coast lands.

The Monkey Hill level at Panama, which rises from 50 feet at the sea to 100 feet a few miles inland, seems to be a widely distributed topographic feature. This level is the result of the degradation of the land down to marine base level, followed by subsequent elevation to its present height. This level is well defined along the Limon coast of Costa Rica, where are seen the same low-topped hills projecting above the swamp plain as at Colon, presenting exactly the same characters of composition and topography. While I could not trace these

[1] In this connection the reader is referred to an admirable chapter on this subject in Professor Suess's "Das Antlitz der Erde," Vol. I. pp. 692–710.

phenomena along the intervening coast line between Colon and Port Limon, there can be but little doubt from the descriptions of Gabb that the same phenomena are extensively developed throughout that region. A study of the hydrographic chart of the Chiriqui lagoon shows that the vast number of islands in that region, as well as the adjacent mainland, are marked by numerous low escarpments and flat-topped terraces corresponding to those of the Monkey Hill level. Maack has also described certain low hills near the mouth of the Atrato which are strongly suggestive of the continuation of the Monkey Hill bench in that direction.

It is difficult to correlate the phenomena of the Pacific side with those of the Atlantic, owing to the great difference in the lithologic composition of the respective coasts, resulting in the variation of the topographic expression, as well as the fact that the entirely different tidal waves have produced on the opposite sides at synchronous epochs quite different details of topography. I have called attention, however, at Panama and the islands of Panama Bay along the entire coast to Punta Arenas, as well as on the Coiba and Jicaron Islands, to the persistent occurrence of a low bench about 100 feet above the tide. These phenomena everywhere present the appearance of an ancient base levelled plain, corresponding in altitude to the Monkey Hill level of the Caribbean coast. It is also interesting to note that, extending far up the Reventazon River of Costa Rica, there are extensive playas or flat valleys in the cañons which apparently represented the old base level of that stream at the time the Monkey Hill bench was down to the sea. The occurrence of these levels on both sides of the continent is very suggestive of the fact that a general uniform regional elevation, whereby these areas, which were near sea level at the time that the swamp levels were beneath its surface, have been brought up to their present height.

A still older and higher base level may be possibly represented in the San Mateo Plain, lying between Punta Arenas and the Aguacate range of mountains of Costa Rica. This certainly has the aspect of an old base levelled plain which has been elevated from near sea level to its present height of from 700 to 900 feet, but the fact that it is composed of rolled volcanic débris somewhat modifies this hypothesis, for it would be just as reasonable to imply that this plain had been built up by volcanic ejecta, and hence I shall not present a positive opinion that any continental elevation may be interpreted from its occurrence.

There is little reason to doubt that the entire Isthmian region after

the close of the mountain making epoch of late Miocene time, has participated in certain regional movements by which its whole area has been alternately elevated and depressed, but the amplitude of these phenomena is such that they cannot have produced any condition by which the Isthmian barrier was destroyed and the waters of the two oceans between them united.

From the similarity of these base levellings, valley forms, altitude of marine deposits, and resemblance of aggradational formations on both the Atlantic and Pacific sides, there can be no doubt that these events took place after the paroxysmal period of Isthmian deformation, and represent the etching and gradation on opposite sides of a great land barrier between the oceans which then existed, as to-day, and there can be no doubt from the present position of both the Pliocene and Pleistocene, deposited unconformably against the older Tertiary formations, that the Central American and Isthmian land masses were well defined before these later epochs.

The low passes across the summits of the Isthmus are not marine, but are solely and simply the work of the downward erosion of the headwater streams of the opposing drainage systems, and this lowering is still in progress. The lowest known pass across the drainage divide of the Isthmus is that of the Culebra, along the line of our section, and, while the waters of the ocean approached this divide much nearer than to-day, the amplitude of the subsidences was never sufficient to have submerged it.

The last event in the Isthmian history was the widely extended epeirogenic movement which resulted in the slight elevation of Post-Pleistocene time, — a movement which is traceable from New England to the mouth of the Orinoco, and which was participated in by the Antilles, resulting in well known phenomena of all these regions.

The events of the periods of time embraced in the inseparable Pliocene, Pleistocene, and recent epochs were undoubtedly accompanied by three results : —

1. Extensive erosion and base levelling of the newly heightened land following the orogenic revolution of late Tertiary time. During this earlier epoch the great valleys of the Tuyra, Atrato, and Chagres were probably largely made. The Monkey Hill and Panama benches probably represent the marginal plains of this erosion period, which may be assigned to late Pliocene time.

2. Subsidence (epeirogenic lowering), accompanied by the conversion of the previously made erosion valleys into the tide water estuaries, and

the drowning of Panama Bay. This resulted in marine littoral sedimentation within the indentations of both the coasts. This event took place in Pleistocene time.

3. An emergence in Post-Pleistocene or recent times by which the former continental outline was partially but not entirely restored.

Résumé of the History of the Tropical American Mainland.

We can now compare the biological deductions with the known geologic facts.

Obscurity of the Paleozoic Record. — It is impossible to make any serious deductions concerning the relations of the North and South American continents during those epochs preceding the Jurassic period, owing to the lack of data.[1]

Possibility of Continuous Land in Jurassic and Cretaceous Time. — There is really some foundation for an hypothesis that the continents were somewhere united shortly after the close of the Paleozoic. We do not mean to assert that that was the case, but the following evidence is worthy of serious consideration.

Probable Absence of Known Jurassic Sediments on the Atlantic Sides of the North and South American Continents. — There is a possibility that the larger portions of both the North and South American continents were land areas during the Jurassic period. Not a single marine Jurassic species has ever been found in the rocks of North or South America east of the Rocky Mountain front or Andean Cordilleras. From my researches on this subject, — unless the beds of the Wealdan epoch, which are classified with the Cretaceous by most authorities, represent the uppermost beds of the Jurassic, as Prof. O. C. Marsh maintains, — I am convinced that in the North American continent land persisted throughout the eastern half of the United States during the Jurassic, and that this land, which was subsequently invaded by the Cretaceous seas, was far greater than the present continental expanse. The occurrence of Wealdan littorals (Lower Cretaceous shore lines) in Brazil is also indicative of large land masses in the South American continent during the Jurassic period.

[1] W. B. Scott, in his recently published work entitled "An Introduction to Geology," p. 39, 1897, says: "It has been suggested that [in Devonian time] a north and south ridge of land extended from Wisconsin all the way to South America, dividing the American seas into Eastern, Interior, and Western. . . . This suggestion has not yet been definitely confirmed, but it may represent the truth."

As a further proof of the fact that the continental land masses were large and extensive during the Jurassic period, we have the indisputable testimony that on the Pacific coasts of both the North and South American continents there is an extensive development of fossiliferous marine littoral Jurassic beds, which grade up without break into the Cretaceous formations of the Pacific province which were deposited against a land barrier.

Furthermore, it is very probable that the Pacific shore lay much farther to the eastward during this period than at present, for, as will be shown in our discussion of the Cretaceous, beds of Pacific sedimentation occur in the Mexican peninsula at Catorce, far eastward of the present Pacific shore line. These beds were undoubtedly derived from an eastward lying land, and the Pacific at the beginning of the Cretaceous epoch covered a large portion of the Mexican region.

Fossiliferous Jurassic beds are now known to occur on the western or interior side of the Eastern Cordilleras in Mexico and Trans-Pecos, Texas, at Catorce, as noted by Aguillera, Miquehuana and Monterey, as seen by the writer, and at Malone, Texas, as recently reported by Cragin. The oceanic affinities of these beds are as yet unpublished, but geographically they belong to the great interior basin region, and not the Atlantic slope.

A. Agassiz has shown that the deep-sea echinoid fauna of the Caribbean and Gulf of Mexico contains a mixture of Mesozoic Pacific types. This fact may suggest that there was an oceanic passage across Central America in Jurassic time, and that the continental bridge, if it existed, may have then been in the Windward region. The discussion of this conjecture, however, must be postponed until a future paper.

The Cretaceous. — The records of the Cretaceous period also present evidence which suggests a possibility of the existence of a complete land barrier between the two oceans. The Cretaceous rocks are highly fossiliferous, and are the first in ascending series affording sufficient paleontologic data upon which to base a discussion of the past relations of the two great oceans.

Discordance of the Faunas of the Atlantic and Pacific Provinces. — Active research of recent years has resulted in the conclusion that, of the many hundred species occurring in the large faunas of the Lower and Upper Cretaceous sediments of the Atlantic and Pacific provinces of the United States, not one species has been found in common with the faunas of the two oceans. So marked is this difference that it is the most impressive fact which has been encountered by recent students of these forma-

tions. We can now clearly separate the Cretaceous formations of the United States into two distinct but synchronous provinces, — those of Atlantic and Pacific sedimentation respectively.

In the State of San Luis Potosi the basal (Neocomian) beds of the Pacific Cretaceous fauna are found lying beneath those of the Comanche (Neocomian) of the Atlantic sedimentation of the Texas region. Above this point there is no trace of community of fossil forms of the Atlantic and Pacific regions. It has been argued that near the close of the Upper Cretaceous the great Gulf of Mexico, which at that time spread over much of the present Great Plains region and the Rocky Mountain front, may have had a northern connection in British Columbia through a shallow passage with the Pacific, yet was still separated to the southward; but there are reasons for doubting even this connection.

This dissimilarity between the Cretaceous faunas of the two coasts apparently continued throughout the entire length of the period. "No geographic continuity of their strata has yet been observed, and no satisfactory recognition of their faunal relationship has been made."[1]

Furthermore, the Cretaceous formations of the Pacific coast of the North and South American regions are underlain by Jurassic formations, and are stratigraphically inseparable from them, and even to-day paleontologists are debating the line of limitation between them, while on the Atlantic side, in the United States at least, the lowest Cretaceous is everywhere, so far as known, unconformably deposited on a pre-existing land area, composed of geologic formations of various ages.

In South America, although the faunas and formations have not been so extensively studied, apparently the same great dissimilarity existed in Cretaceous time between the life of the Pacific and Atlantic waters. Of the three hundred or more species from the Pacific sediments, it is doubtful if any are identical with the forms found in Brazil or the West Indies.

The Cretaceous faunas of the Pacific coast of North America contain a rich fauna of abundant species having an individuality of its own, closely related to the Trans-Pacific faunas of Russia and Western Europe, but absolutely distinct from the synchronous beds deposited on the other side of a great continental barrier in the waters of the Atlantic.

On the Atlantic side of the Andes in Colombia and Ecuador and parts of Brazil, the little that is known of the Cretaceous fauna is thoroughly suggestive that it is largely eastern in its facies, presenting some resemblances to the Atlantic Cretaceous of the United States, which, when the

[1] C. A. White, "Correlation Papers, Cretaceous," pp. 197, 198.

latitudinal differences are considered, are striking.[1] In Colombia such forms as Gryphæa vesicularis, several species of Ammonites figured by Karsten, and the Foraminifera, show a resemblance to the Lower and Middle Cretaceous of Texas, while the Ammonites described by Hyatt from Sergipe were referred by him to genera and species occurring abundantly in the Cretaceous of Texas, but unknown to the Californian fauna.

The Antillean Cretaceous cannot here be discussed, for it has not as yet been sufficiently studied, but will be defined in our forthcoming studies on the island of Jamaica. This is characterized, like the Tertiary formations, by certain variations of fauna due to the environment and the absence of continental sediments in the waters which these species inhabited.

The Cretaceous faunas of Jamaica, which have been studied in the past by others and which I have personally investigated, while specifically different from those of the United States, apparently do not contain a single species which has been found on the Pacific coast. The same may be said of the Cretaceous of Santo Domingo, Cuba, and Trinidad, which localities include all we know of the West Indian Cretaceous.

In the States of Guatemala and Chiapas, Sapper has demonstrated and mapped the occurrence of the Cretaceous formations, apparently of Atlantic facies, possessing the peculiar genus Barrettia, which has hitherto been found only in Jamaica.

In the vast stretch of Isthmian country lying between Guatemala and the Venezuelan coast, no outcrop of the Cretaceous has been reported except the one near San José, Costa Rica, described in this report.

D'Orbigny's conclusions that the oceans were united across the Isthmus in Cretaceous times were based upon his identification of five of the Cretaceous fossils from the western side of South America with five in the Paris Chalk. The remarkable differences between the synchronous Lower and Middle Cretaceous faunas of the California and Texan region on the one hand, and the Andean and Venezuelan-Brazilian provinces on the other, are so great that in our opinion the only interpretation that can be placed upon them, notwithstanding the absence of good fossiliferous Cretaceous localities in Central America, is that the waters

[1] Since this paper was written an excellent résumé of the Cretaceous faunas of Peru, Venezuela, and Colombia has been printed from the pen of Dr. Gustav Steinman, entitled "Beiträge zur Geologie und Paleontologie von Südamerica," Stuttgart, 1897. It revises the determinations of Karsten, Stellner, and others, and presents comparisons and conclusions which the reader should consult.

of the Atlantic and Pacific were probably separated in the Tropical American region during this epoch.

While it is probable that a land barrier existed between the two oceans in Cretaceous time as now, we do not wish to be committed to the assertion that the geographic outline of this barrier is in any way recognizable in the present conformation of the Isthmian areas, for certain data lead us to believe that subsequent revolutions may have completely changed its location, if it ever existed.

An illustration of the probability of the vast changes of the land since the beginning of Cretaceous time is found in Mexico. The present area of this Republic was a great battle ground in Cretaceous time between the migrations of the waters of the Pacific and the Atlantic, but from the character of the faunas it is apparent that this barrier, though migratory, was constantly maintained. The sedimentary formations, with the exception of small exposures of the Paleozoic in the extreme northwest and a narrow fringe of Tertiary along the shore of the Mexican Gulf, are predominantly of the Cretaceous period. The present position of the outcrop of the oldest Cretaceous formations in Mexico (those recently described as in part Jurassic by Castillo and Aguillera from Catorce) shows that the waters of the Pacific in the latitude of the Tropic of Cancer reached eastward across the Mexican peninsula at the beginning of Cretaceous time, nearly to the locus of the present shore of the Gulf of Mexico, and were opposed in that direction by the Jurassic land; while in Middle Cretaceous time, however, along the boundary region between Mexico and the United States, the Atlantic waters extended westward across the Republic far into the State of Sonora and within a few degrees of the present Gulf of California. This peculiar shifting of geographic relations in Cretaceous time has been well stated by Mr. Stanton :—

"With the occurrence of the Pacific Lower Cretaceous fauna at Catorce, not a great distance from the Gulf of Mexico, and of the Texas or Gulf fauna in Sonora, much nearer to the Pacific, the question as to how the two faunas were kept separate becomes still more difficult. From the data now at hand the most plausible hypothesis seems to be that the sea transgressed the continent, first from one side, and then from the other, but never quite crossed the shifting barrier."[1]

So that we may conclude that the waters of the Atlantic and Pacific were probably as completely separated by a great continental land bar-

[1] Journal of Geology, Vol. III. No. 7, p. 861, October–November, 1895.

rier in Cretaceous time as they are to-day, a proposition fully as tenable as the opposite hypothesis that they were united.

Evidences of Marine Connection in the Tertiary Period. — The independent opinions of Agassiz, Dall, Verrill, Moore, Etheridge, Gabb, Scott, and Bland all tend to conclude that the oceans were in some manner united in that portion of the Tertiary period prior to the close of the Miocene. In fact, all who have discussed the question from a biologic standpoint, with the exception of Jukes-Browne, place the date of the connection of the two oceans across Tropical America in early Tertiary time.

The researches detailed in the first part of this paper present the first data by which these deductions can be tested in the light of the geologic history, and enable us to fix with greater exactitude the date of the two most important events in Tropical American history, — the epoch of geologic time when common species lived in both the Pacific and Caribbean waters (the date of the union of the waters), and the epoch when they were completely and forever separated by the great Caribbean Tertiary orogenic revolution.

In discussing this period, however, we are at first confronted with the indisputable fact that all the known Tertiary sediments of the Central American and Isthmian region are Atlantic sediments, and that no stratigraphic proof has as yet been discovered by which marine connection can be estabished.[1] Hence all deductions must be limited to paleontologic evidence.

It is an interesting fact that, around the great curve of the Caribbean and thence eastward along the northern coast of Colombia and Venezuela, the older Tertiary formations are all of the same lithologic aspect as those bordering the Atlantic and Gulf States of the North American continent.

If the early Tertiary littoral completely bordered the Yucatan procontinent, then marine waters existed between the Chiapas-Yucatan mainland and the Western Antilles, and no bridge between them and the Antilles could have possibly existed at that time. Upon this problem we are not at present prepared to state an opinion. It is impos-

[1] Dr. J. W. Spencer has recently inferred Pleistocene connection across the Isthmus of Tehuantepec. His deductions are based upon the occurrence of gravel covered streamways in the summit divide of Cretaceous rocks which separate the lower lying coastal formations of later date. No evidence is presented, however, to show the marine affinities of these features, and from his data our conclusions would be that the Tehuantepec Isthmus has remained land since its earliest origin. See Bull. Geol. Soc. of America, Vol. IX. pp. 13–34, Rochester, 1897.

sible to avoid the conclusion that the Tertiary sediments were derived from a near-by land which existed at the time of their deposition. Could they have been derived from some land which once existed to the northward in what is now the bosom of the Caribbean? In that direction we are confronted by great depths. If we turn to the South American continent as the source of this sedimentary débris we are again confronted by certain facts which oppose this hypothesis. The narrow belt of country shows that the sediments derived from the ancient Andean and Venezuelan highlands in Tertiary time were deposited along its own coast. If we endeavor to argue that the westward flowing currents of the Caribbean could have distributed these sediments along the Isthmian region, then we must also acknowledge that there must have at the same time existed some littoral barrier against which they were deposited. Turning to the Central American region lying to the westward, as a source of these sediments, we are confronted by the absence of any structural evidence of a watershed trending southward which could have deposited them over the Isthmian region. The only hypothesis that can fit the condition of their present lay and arrangement is that they were derived from an adjacent land, and this land may have existed to the southward towards the Pacific coast, or in the area now covered by the Pacific waters of the Isthmian region, — a land which has disappeared as the land which once covered Panama Gulf is disappearing to-day.

The fact that a series of marine sediments of Eocene and Oligocene Tertiary age at intervals fringes the Caribbean coast from the San Juan at Graytown, Nicaragua, to Cartagena on the northern coast of Colombia, and that these have been distorted and intruded by igneous rocks, by no means demonstrates that dry land did not exist toward the Pacific side of the Isthmian region during the Eocene and Oligocene epochs of deposition. In fact, there are reasons to show that these sedimentations and disturbances may have taken place marginally against an older land during these epochs.

We know beyond doubt that the Atlantic Tertiary sediments of the North American continent constitute a fringe which extends considerably inland from the present outline of the Atlantic Ocean as far south as the end of the Mexican Cordilleras. We also know that a very narrow ribbon of Tertiary sediments borders the Pacific coast of California, but is only doubtfully represented to the south along the margins of Mexico to the Isthmus of Tehuantepec. It is known that these sediments of both coasts as far south as Tehuantepec were laid down against a

great and continuous pre-existing Cordilleran continental barrier. What proof have we that this central barrier land may not have largely continued southward and continued to separate the oceans in Tropical America, with the exception of a shallow passage or two barely sufficient to permit the migration of littoral faunæ?

Absence of Rocks indicating Off-shore Deposition in the Tropical American Mainland. — Had deep marine connection existed across the Isthmus of Panama in Tertiary time there should surely be preserved in the region some rocks indicative of other than shallow deposition within this hypothetic channel. Future observers may find them, but the experience of those of the past have not been fruitful in this direction. Nowhere in the Tropical American mainland except along the marine side of Yucatan has a single rock of Post-Cretaceous age been found which indicates other than shallow near-shore deposition. The Empire limestones are littoral and clearly composed of triturated oceanic débris, alternating with impure sediments bearing plant remains.

Absence of Known Tertiary Sediments on the Pacific Side of Tropical America. — There is no positive record of Tertiary sediments having ever been observed at any point on the vast stretch of the Pacific seaboard of the Tropical American region south of the peninsula of Lower California. Exploration has been deficient in this region however,

Paleontologic Evidence of Marine Connection in Tertiary Time. — The various fossiliferous horizons of the Tertiary series described in this paper, in general are thoroughly Atlantic in their facies, the overwhelming majority of species of all the terranes being those found only within the sediments of known Atlantic origin. A single terrane, however, furnishes an admixture of Pacific species in the fauna which affords the only direct paleontologic evidence resulting from our explorations which indicates relationship between the two oceans past or present. Five species of mollusks, noted by Dr. Dall in the Gatun (Vamos á Vamos) beds of Eocene Tertiary, also occur in the Tejon Eocene of California. The presence of these species is evidence that in the Claiborne Tejon epoch there was at least shallow communication, and hence to this epoch alone can the date of an interoceanic connection be assigned by direct paleontologic evidence.

Lack of Testimony showing that the Eocene Passage was other than Shallow and Restricted. — None of the data presented by previous writers, however, nor any of my own observations, are sufficient to show that such a connection was of other than a shallow and restricted character.

The Culebra clay of supposedly Eocene age, which we have hypothetically correlated with the great coal formation of the Caribbean side of the Isthmian region, is the only sedimentary formation which occurs near the drainage divide of the oceans, and this is found only on the Caribbean side. The composition, structure, and fossils of these clays give no evidence of their deposition in a passage connecting the oceans, especially a deep and extensive one. These clays are apparently entirely void of molluscan remains such as surely would have inhabited such a passage. In fact, their composition, made up so largely of land débris and plants, and their extensive distribution, are, in my opinion, capable of but one interpretation, that, instead of indicating a free marine passage, they attest the existence of larger surrounding land areas in this region than now exist.

Although the biologic and paleontologic evidence leads to the conclusion that a shallow connection did exist somewhere in Tropical America during Eocene time, neither the geologic nor the biological evidence shows conclusively that the Isthmus of Panama was the exact place of this connection. It merely proves that such a connection was probable somewhere in that vast Tropical region between the known localities of the Tejon beds in Lower California and the place of the occurrence of the Gatun beds on the Caribbean side near Colon.

The occurrence in the Tertiary of a few species common to the Atlantic and the Pacific have been reported by G. B. Harris as far northward as Galveston, Texas. A connection of the two oceans in Tertiary time in that latitude, from the well known evidence of the geological formation and history, would be preposterous.

The Oligocene and later faunas of the continental coast succeeding the Claiborne, so far as the writer is aware, are thoroughly Caribbean, and show no evidence of free commingling of species of the two oceans.[1]

Harmony of Geologic Evidence with Biologic and Paleontologic Deductions that Land Connection was thoroughly established during the Close of the Miocene. — If the marine passage ever existed across the Isthmus or elsewhere in Tropical America, it must have been during the later Eocene epoch, for all evidence concerning later epochs shows that the great land barrier connecting the continents has existed since that time, and that the seas have never since communicated across it. Hence the

[1] It has been alleged by several writers upon paleontology that Pacific forms — especially corals — do exist in the Miocene (Late Oligocene) fauna of the Great Antilles. We have proofs that many of the specific correlations were erroneous. This subject will be discussed in our report on Jamaica.

conclusions of most authorities that there was a land barrier between the oceans at the close of the Miocene period is in perfect harmony with the geological deductions of this paper. The mountain making epoch of the Isthmus, as shown on previous pages, which was but a part of a great orogenic revolution that affected the entire perimeter of the Great Antilles and the Caribbean, can be definitely fixed in that interval of time between the close of the Oligocene[1] and the beginning of the Pliocene, as testified by the uncomformable deposition of the sub-horizontal Pliocene rocks against the folded and upturned Oligocene. The vast extent and visible effects of this orogenic movement throughout the Caribbean and Antillean region, and the possibility of the future demonstration of its continuity as far north as the Pacific coast of California, and even Alaska, will lead to a complete readjustment of many current geographic conceptions. In any case, if a passage existed between the seas previous to this time such an orogenic evolution would theoretically furnish every cause for its closure during this epoch.

This testimony of the geologic structure is in harmony with the majority of biologic opinions that the Isthmian barrier established during the close of the Tertiary persisted as a permanent land until the present time.

Biologic and Geologic Deductions oppose the Theory of a Passage in Pliocene or Pleistocene Time. — All the authentic biologic and geologic evidences are entirely opposed to the possibility of a communication between the two oceans across the Isthmian or Tropical American region in Pliocene or Pleistocene time.

The possibility of such a connection has never been seriously maintained on biologic grounds. The deductions from the study of all specialists of the life of the adjacent shores are distinctly opposed to this conclusion.

One of the strongest arguments against the existence of an interoceanic passage during this epoch is the testimony of the present life of the bordering seas. It is a well known fact that the Pleistocene faunas differ so little from the recent that they are almost similar, — the number of identical species being far greater than the distinguish-

[1] The use of the term Oligocene throughout this report, upon the authority of Dr. Dall, is somewhat of an innovation in American usage of Tertiary nomenclature. It includes the beds equivalent to the Vicksburgian or upper part of the Eocene and the lower part of the Miocene of older usage. Hence in many instances its use may be synonymous with the term Miocene of many previous authors as applied in Tropical America, especially by Gabb, Guppy, and European paleontologists.

ing forms. The recent faunas of the opposite side of the Isthmus are so distinct from each other that the only logical deduction that can be made from the few identical species is that they are the survival of a communion of waters which took place in very remote time.

On the contrary, if there had been communion at so late an epoch in Pleistocene time, the present species of the opposing sides of the Isthmus would so resemble each other that they would hardly be distinguishable. The testimony against this Pleistocene connection is strongly presented by all sides of biologic research.

The species and genera of corals of the two faunas of the Atlantic and Pacific coast, according to A. E. Verrill,[1] are entirely distinct, a conclusion with which Mr. Gregory fully concurs, who expresses himself against a submergence of the Isthmus since Pliocene times.[2]

Belt[3] states "that the mollusca on the two coasts, separated by the narrow Isthmus of Darien, are almost entirely distinct. . . . In the Caribbean province, which includes the Gulf of Mexico, the West Indian Islands, and the eastern coast of South America, as far as Rio de Janeiro, the number of marine shells is estimated by Prof. C. E. Adams at not less than 1,500 species. From the Panamic province, which, on the western coast of America, extends from the Gulf of California to Payta in Peru, there have been catalogued 1,341 distinct species of marine mollusca. Out of this immense number of species, less than fifty occur on both sides of the narrow Isthmus of Darien. So remarkably distinct are the two marine faunas, that most zoölogists consider that there has been no communication in the Tropics between the two seas since the close of the Miocene period, whilst the connection that is supposed to have existed at that remote epoch, and to account for the distribution of corals, whilst advocated by Professor Duncan and other eminent men, is disputed by others equally eminent. No zoölogist of note believes that there has been a submergence of the land lying between the Pacific and the Atlantic since the Pliocene period. See also Gregory[4] for the mollusks, and Fisher,[5] Jordan,[6] and Evermann and

[1] Proc. of the Essex Institute, 1866, p. 323.

[2] "On the Comparison of the Coral Faunæ of the Atlantic and Pacific Coasts of the Isthmus of Darien, as bearing on the supposed Former Connection between the two Oceans." American Naturalist, Vol. III. p. 500 (1869).

[3] "Naturalist in Nicaragua," page 264.

[4] Quart. Journ. Geol. Soc., Vol. LI. No. 203, pp. 302, 303, London, August, 1895.

[5] P. Fisher, "Manuel de Conchologie," 1887, p. 168.

[6] David S. Jordan, "A List of Fishes known from the Pacific Coast of Tropical America, from the Tropic of Cancer to Panama," Proc. U. S. Nat. Mus., Vol. VIII. pp. 361–394, especially pp. 393, 394 (1885).

Jenkins,[1] for a comparison of the fishes. From the study of much larger collections than those available to Dr. Gunther, Jordan reduced the number of species common to the two faunas to six per cent, and declared that they were so 'substantially distinct' that no recent connection between the seas had existed. Evermann and Jenkins consider the Pacific fish fauna as composed of 1,307 species, and, excluding 16 species of such wide distribution that their evidence does not count, they estimate that only 4.3 per cent are common to the two shores. Dr. Dall has also summarized some facts upon this subject."[2]

One of the strongest arguments against the Isthmian marine passage in Pleistocene time, as alleged by some, or a profound subsidence of the whole region, as has been argued by Spencer, is the testimony of the vertebrate remains of Nicaragua. According to Professor Cope,[3] these remains show a well defined mingling of South American Pampean and North American faunas, the former being represented by Hydrochœrus and Toxodon, the latter by Bos, Equus, and Elephas. Surely this mixture of the two continental faunas of the Pleistocene epoch premises a land barrier which could not have existed if there had been any extensive submergence in this epoch.

Conclusion.

In the foregoing pages I have endeavored to present all the facts known upon the geological history of the Isthmian region. We have shown its antiquity by the interpretation of its topography. This antiquity is stamped upon every form. We have shown that as far back as Cretaceous time there is evidence of nucleal rocks, and that there was a striking dissimilarity in the sediments and life of the adjacent oceans to that existing to-day. We have shown that the igneous rocks both eruptive and intrusive were buried and are now exposed by erosion. The volcanic fires, which still persist eastward in the Andean heights and to the westward in the Central American plateau, have long ceased to exist throughout the Isthmian region. Since the Pliocene Tertiary, at least, the region has been one of volcanic quiescence.

1 B. W. Evermann and O. P. Jenkins, "Report upon a Collection of Fishes made at Guaymas, Sonora, Mexico, with Descriptions of New Species," Proc. U. S. Nat. Mus., Vol. XIV. No. 846, p. 126 (1891).

2 Bull. U. S. Geological Survey, No. 84, 1892, Wm. H. Dall, pp. 151, 152.

3 This opinion by Professor Cope, already stated in his writings, was reaffirmed by him in a personal conversation, the substance of which was written down and approved by him a few weeks previous to his death.

By elimination, we have concluded that the only period of time since the Mesozoic within which communication between the seas could have taken place is the Tertiary period, and this must be restricted to the Eocene and Oligocene epochs of that period. The paleontologic evidence upon which such an opening can be surmised at this period is the occurrence of a few Californian Eocene types in the Atlantic sides of the Tropical American barrier, within the ranges of latitude between Galveston (Texas) and Colon, which are similar to others found in California. There are no known structural data upon which to locate the site of this passage, but we must bear in mind, however, that this structure has not been completely explored.

Even though it was granted that the coincidence of the occurrence of a few identical forms on both sides of the Tropical American region, out of the thousands which are not common, indicates a connection between the two seas, there is still an absence of any reason for placing this connection at the Isthmus of Panama, and we could just as well maintain that the locus thereof might have been at some other point in the Central American region.

The reported fossil and living species common to both oceans are littoral forms, which indicate that if a passage existed it must have been of a shallow and ephemeral character.

There is no evidence either from a geologic or biologic standpoint for believing that the oceans have ever communicated across the Isthmian regions since Tertiary time. In other words, there is no evidence for these later passages which have been established upon hypothetical data, especially those of Pleistocene time.

The numerous assertions so frequently found in literature that the two oceans have been frequently and recently connected across the Isthmus, and that the low passes indicative of this connection still exist, may be dismissed at once and forever and relegated to the domain of the apocryphal. A few species common to the waters of both oceans in a predominantly Caribbean fauna of the age of the Claiborne epoch of the Eocene Tertiary is the only paleontologic evidence in any time upon which such a connection may be hypothesized.

There has been a tendency in literature to underestimate the true altitude of the Isthmian passes, which, while probably not intentional, has given encouragement to those who think that this Pleistocene passage may have existed. Maack[1] has erroneously given the pass

[1] Harper's Magazine, 1873, p. 803.

at 186 feet. Dr. J. W. Gregory[1] states "that the summit of the Isthmus at one locality is 154 feet, and in another 287 feet in height." The lowest Isthmian pass which is not a summit, but a drainage col, is 287–295 feet above the ocean.[2]

If we could lower the Isthmian region 300 feet at present, the waters of the two oceans would certainly commingle through the narrow Culebra Pass. But the Culebra Pass is clearly the headwater col of two streams, the Obispo flowing into the Chagres, and the Rio Grande flowing into the Pacific, and has been cut by fluviatile action, and not by marine erosion, out of a land mass which has existed since Miocene time. Those who attempt to establish Pleistocene inter-oceanic channels through this pass on account of its present low altitude, must not omit from their calculations the restoration of former rock masses which have been removed by the general levelling of the surface by erosion.

Summary.

There is considerable evidence that a land barrier in the Tropical region separated the two oceans as far back in geologic history as Jurassic time, and that that barrier continued throughout the Cretaceous period. The geologic structure of the Isthmus and Central American regions, so far as investigated, when considered aside from the paleontology, presents no evidence by which the former existence of a free communication of oceanic waters across the present tropical land barriers can be established. The paleontologic evidence indicates the ephemeral existence of a passage at the close of the Eocene period.

All lines of inquiry — geologic, paleontologic, and biologic — give evidence that no connection has existed between the two oceans since the close of the Oligocene. This structural geology is decidedly opposed to any hypothesis by which the waters of the two oceans could have been connected across the regions in Miocene, Pliocene, Pleistocene, or recent time.

[1] Quart. Journal Geol. Society of London, Vol. LI., Part 2, No. 203, page 299, 1895.

[2] The height in feet of the natural passes of the Isthmus of Panama, according to known engineering data, are as follows: Culebra, 287-295; Atrato-Sucubti, 583; Atrata-Napipi, 778; Caledonia Pass, 1,003; San Blas, 1,142; Atrata-Morte, 1,143. The Nicaragua Pass is 147 feet; Tehuantepec, 858; Honduras, 2,956.

PART VI.

Appendices.

Report by Dr. William H. Dall upon the Paleontology of the Collections.[1]

I have examined the fossils from the Isthmus of Panama and Costa Rica submitted by you, and now send you my conclusions. From the fauna and lithologic character the different horizons appear to be as follows: —

A. Altered, partly recrystallized, limestone, (Nos. 14, 21, and 22,) near Empire. Probably Tertiary, perhaps Eocene.

B. Shale with Orbitoides forbesii (No. 1). This would naturally fall about the Vicksburgian horizon, or lower Oligocene, but if it is positively below the Gatun or Vamos á Vamos beds it cannot be newer than the Lower Claiborne Eocene. The Foraminiferal fauna would fall in much more naturally above the fauna of the Gatun beds, and I should suspect a fault or overturn unless an inferior contact was actually observed.

C. Vamos á Vamos or Gatun beds. From the number of species common to this series and the Claiborne sands, as well as the Upper Tejon of California, there seems no escape from regarding this horizon (Nos. 18, 19, 26) as Clairbornian, or Upper Tejon, Eocene. The alternative that these beds range above the Vicksburgian seems decidedly less acceptable. In that case we should have to regard the species referred to as being unaccountable survivals.

D. Mindi Hill beds. This is a deep water deposit, and may have been laid down in deep water at the same time that the Gatun beds were being formed nearer the shore. The age is probably Claibornian Eocene (No. 4).

E. Monkey Hill beds. — (Nos. 29, 48, 49, 87.) These are middle or upper Oligocene and agree with the so called Miocene of St. Domingo, Haiti, Trinidad, Curaçoa, Jamaica, and the Chipola fauna of West Florida. They contain a number of species in common with all these and with the Gatun beds, but by the loss of some of the more Eocene types and the acquisition of a number of modern forms are certainly

[1] Since this Report was submitted, Dr. Dall has published a paper containing notes on the collections described. See Descriptions of Tertiary Fossils from the Antillean Region, Proc. U. S. National Museum, Vol. XIX. pp. 303-331, 1896.

newer than the latter. The following notes in detail were made. I would note that I have many undescribed species from the West Indian Oligocene, which horizon until lately, in common with others who have written about it, I have called old or warm water Miocene. The beds which I identified as Miocene from your Cuban collection are also Oligocene. For this reason I am in many cases able to state that the same species occur in both of two localities, while I cannot as yet name it specifically.

A. *Empire and Vicinity.*

This limestone has the appearance of the Everglades limestone of Florida and has in part been deposited or recrystallized from a solution, perhaps of its own upper portion. It contains traces of corallines and other obscure organisms, probably Foraminifera; fish bones and one valve of a Pecten, subgenus Janira. Neither of these is in a state to identify more particularly, but the Pecten looks modern, and is probably not older than the Eocene.

B. *Foraminiferal Shale or Marl.*

This contains a faint impress of a bivalve shell, perhaps a Cardium, and many specimens of Orbitoides forbesii Cpr. This species is common to the Eocene and Oligocene, being abundant in the Caroni beds [1] of Trinidad and the Bowden beds of Jamaica,[2] which have hitherto been referred by everybody to the Miocene. If this bed was on top of the Gatun beds they might easily be referred to the Claibornian, and this to the Vicksburg, or even higher. If, as I understand from your section, it is below the Gatun beds, the Claibornian element in their fauna might possibly be regarded as a survival. According to Mr. R. M. Bagg, I understand this bed also contains Cristellaria lenticula Reuss, Bulimina ovata d'Orb., Gaudryina reussi Stache, Sagrina striata Schn., and Truncatulina sp., none of which is characteristic of any special horizon.

[1] In his earlier papers Mr. R. J. L. Guppy may have published this species as being abundant in the Caroni beds of Trinidad, thereby misleading Dr. Dall. In Guppy's latest publication, however, the position of Orbitoides forbesii Cpr., and its associated foraminiferal fauna, is shown to belong to the lower lying, or Eocene, Naparima beds. See Quart. Jour. Geol. Soc. London, Vol. XLVIII. pp. 519, 520, 523, 524, *et seq.* — R. T. H.

[2] Our researches in Jamaica, made since Dr. Dall's report was prepared, together with careful study of the material by Prof. R. M. Bagg, show conclusively that Orbitoides does not occur in the Bowden beds, their range being confined to the lower horizons. — R. T. H.

C. *Vamos á Vamos or Gatun Beds.*

Species were described from these beds by Conrad many years ago, and later by myself. They have a rich fauna, but the fossils are all pseudomorphs in calcite, in a tough matrix, and difficult to extract in good condition. They contain a number of what have hitherto been regarded as typical Claibornian species, some of which are common to the Upper Tejon of California. Notwithstanding the fact, if it be a fact, that they are found above the Orbitoides bed (B), which has a distinctly Oligocene facies, I am obliged to regard them as Eocene. If it were not for this stratigraphic puzzle I should refer them to the Claibornian without hesitation. The species common to the Claiborne sands are as follows: Lapia perovata Conr., Solarium alveatum Conr. Natica (Lunatia) eminula Conr., a small Sigaretus or Naticina, Neverita sp., and Cerithiopsis sp. Solarium alveatum and Natica eminula, with Turritella gatunensis (+ uvasana Conr.), and the genus Glyptostyla, are also common to the Upper Tejon of California. A careful study of the Gatun fauna might reveal other common species of Claiborne origin.

The following genera were noted in the Gatun shale on a rapid examination of your material: Atys, Cylichna, Conus (2 sp., *not* Oligocene), Glyptostyla (panamaensis Dall), Phos, Nassa, Neverita (gibbosa Lea), Lunatia (eminula Conr.), Natica (sp.), Ampullina, Lupia (perovata Conr.), Turritella (gatunensis Conr.), Solarium (alveatum Conr.), Oniscia, Galerus, Trochita, Capulus, Niso, Scala, Phasianella (small sp.), and two species of Dentalium. Among Pelecypods we find: Nucula (large sp.), Leda (like acuta), Adrana, Arca, Pecten (like Poulsoni), Lucina (like crenulata), Diplodonta, Loripes, Chama, Cardium (haitensis), Cardium (large sp. like muricatum), Cardita (like a small Claiborne sp.), Venus (mactropsis Conr.), Venus (wallii Guppy), Dosinia, Tivela, Cytherea (dariena Conr.?), Cytherea (sp.), Clementia, Lucinopsis, Mactra, Solen, Tellina (dariena Conr.), Tellina (sp.), Semele, Lyonsia, Corbula (3 sp.), and a Thracia, like undulata, but distinct. The assemblage might live in 10–30 fathoms.

D. *Mindi Hill Greensand.*

The species in this material, without exception, have a deep water facies and are such as we might expect to find in 50–200 fathoms, or even more. The following genera are represented: Cylichna, Pleurotoma, Astyris, Turritella, Cerithiopsis, Solarium (alveatum Conr.),

Dentalium, Arca, Divaricella, Cryptodon, Cardium, Venus or Cytherea (small thin form), Callocardia, Corbula (vieta Guppy), Pholadomya? (fragment).

E. *Monkey Hill Beds.*

These are of a softer, more evenly grained rock than the Gatun beds, and in the greensand grains recall the Mindi Hill, but the species of Monkey Hill fossils belong in shallower water, and there are many which agree with those found in St. Domingo, Trinidad, Jamaica, etc. There can be no question as to their age, as they are connected with the Chipola through having in common species found in Jamaica (Bowden beds). The genera observed in the fossil fauna of Monkey Hill are as follows: Haminea, Conus (one very large sp.), Conus (catenatus Sby., Haiti), Terebra (2 sp., 1 also Chipolan), Pleurotoma (pontonensis Dall, St. Domingo), Pleurotoma (like Henikeni Sby., Jamaica), Pleurotoma (3 sp., 1 also in Haiti), Astyris, Marginella (2 sp.) Phos (3 sp., all also in Haiti), Nassa, Persona, Natica (subg. Cochlis) operculum, Turritella (altilira Conr., like Chipolan sp.), Cerithiopsis, Simnia, Malea (camura Guppy, also St. Domingo and Jamaica), Solarium (quadriseriatum Sby., Haiti), Dentalium (2 sp. also in Gatun beds, Haiti, Jamaica, etc.), Cadulus (sp. also in Haiti), Leda (tedæformis Guppy, two sp., also in Haiti), Arca (consobrina Sby., Jamaica, Trinidad), Pecten (like floridus Hds., also Jamaica), Avicula (atlantica Lane, Jamaica and Pliocene and recent), Lucina (small like crenulata), Cardium (haitense Sby., Curaçoa, Jamaica, Haiti), Cardium (large, with many ribs), Venus (mactropsis Conr., also at Gatun), Dosinia (cyclica Guppy, Trinidad), Cytherea (dariena Conr.? Haiti), Crassinella (martinicensis Guppy, Martinique, Trinidad, Jamaica), Tellina (dariena Conr.), Tellina (sp.), Abra, Thracia (like undulata, also Gatun), Corbula (vieta Guppy, Trinidad, etc.), Corbula (cubaniana d'Orb., Jamaica, also Pliocene and recent).

No. 50 is Pleistocene, mixed with recent and older fossil shells.

Costa Rica.

The Pliocene of Limon has been worked upon by Gabb (who died before finishing his work, so that the list in Journ. Acad. Nat. Sci. Phila., 2d ser., Vol. VIII. No. 4, p. 349, does not cover all he collected), and No. 67 appears to be part of it. It contains Drillia (perspirata Dall), Dolium, Lima (scabra Lam.), and fragments of Vermetus. No. 84 is also Pliocene. No. 83 has mixed Pliocene, Oligocene, and recent specimens. No. 85 appears to be Pleistocene or recent.

I have run over the specimens from Costa Rica. A good many of them contain no fossils. Nos. 88 and 89 (Bonilla) so far as they are fossiliferous have the Monkey Hill (Upper Oligocene) fauna, and while the matrix is coarser the greensand material marked as occurring above them is the same as the Monkey Hill matrix essentially, but contain only unidentifiable fragments of fossils. No. 91, the Guallava sandstone, is interesting. It is Lower Oligocene, and exactly comparable or rather equivalent to our Vicksburgian, containing only Vicksburg species, including the genuine Orbitoides mantelli, Phos, Dentalium, Plicatula anomia, etc., all Vicksburg species.

Report by Prof. R. M. Bagg upon the Foraminiferal Deposits near Bujio, and of the Empire Limestone.

The main mass of the rocks of the specimens forwarded is composed of Orbitoides forbesii Carpenter, which is undoubtedly an Eocene form. Other species identified are: Cristellaria lenticula Reuss; Bulimina ovata d'Orbigny; Gaudryina reussi Stache; Sagrina striata Schnager; Truncatulina sp. indet.

All of the above are Tertiary forms. I have no hesitation in pronouncing the rocks to be of Eocene age.

Regarding the sections of the Empire limestone, it is not easy to determine anything but generic types in sections. These slides you send contain transverse sections of Nummulites, one Orbitoides, Cristellaria or Rotative type, and Nodosaria. It is probably an Eocene rock, as the Nummulites are the predominating type.

Report on the Fossil Corals Collected.

By T. Wayland Vaughan.

Those from the old reef, 1½ miles west of Port Limon, Costa Rica, are: Meandrina filograna (Esper.); Dichocœnia stokesi M. Edwards and Haime; Orbicella acropora (Linn.); Siderastræa sp.; cf. S. galaxea (Pallas).

All of these species are recent as well as fossil.

Notes regarding the distribution elsewhere of these fossil species from the raised reef near Port Limon, can be found in a memoir by Dr. J. W. Gregory.[1]

[1] Quart. Journ. Geol. Soc. London, Vol. LI. pp. 257–285, August, 1895. [See also Verrill's Reports, cited on p. 172. — R. T. H.]

Preliminary Description of the Specimens of Igneous Rocks in the Collections from the Isthmus of Panama and Costa Rica, made by Robert T. Hill, January, February, and March, 1895.

By J. E. Wolff.

(2) Quarry at Bujio. In the slide a much decomposed augite porphyrite. The slide must be from a pebble, for the hand specimen is a conglomerate.

(3) Boulders of hill back of Peña Negra, about one mile below Bujio on Chagres River. Both slides are of hornblende andesite.

(5) Cut north of end of Las Cascadas siding, Panama Railroad. A reddish green granular rock, with green spots and chalcedone lining cavities. Contains fragments of feldspar and of eruptive rock. Silicified tuff.

(6) Panama Railroad, neck below "Nigger Head" Bluff, Mata Chin. Basalt.

(7) First cascade, Las Cascadas. A banded gray flinty rock. In the slide long laths of plagioclase feldspar crystals of magnetite, and abundant black irregular grains, probably the decomposed bisilicate. An eruptive (augite-porphyrite ?).

(8) Panama Railroad from Nigger Head Bluff, Bas Obispo. A decomposed basic eruptive hornblende-augite-andesite, or porphyrite.

(9) 31st mile Panama Railroad. Augite-andesite.

(10) 31½ miles Panama Railroad, Bluff near Haut Obispo. (?) Badly decomposed olivine basalt, or melaphyre.

(11) 33 miles Panama Railroad. First fall of the Obispo River. A reddish gray trachyte with feldspar phenocrysts and green patches.

(12) 32 miles Panama Railroad. Coarse decomposed tuff; augite porphyrite fragments; calcite cement.

(13) 31¾ miles, Panama Railroad cut near Bas Obispo. Tuff with siliceous cement and fragments of decomposed basic eruptives.

(14) 34½ miles, Panama Railroad. Empire cut. Limestone containing shell fragments.

(15) Panama Railroad, miles 32, cut in east and west hill. Dirty green decomposed augite andesite.

(16) Panama Railroad. Drift from high mountain back of Empire limestone, ½ mile north. Dolerite (Basalt).

(19) Panama Canal between Vamos á Vamos and 10½ kilometers. A dark gray limestone containing shells. In a calcareous cement

fragments of hornblende, triclinic feldspar and augite from andesitic lava.

(20) Isthmus of Panama. Miraflores. Same as 23 and 36.

(23) Isthmus of Panama. Barbacoas crossing of the Chagres River. Same as 36.

(24) Cut in Railroad, a mile south of Culebra Station, Panama Railroad. Dirty gray tuff containing fragments of a glassy basalt. Another slide is a fresh diabase of coarse basalt.

(25 and 41a) Panama Canal, summit of Culebra. Dolerite (Basalt).

(30) Panama Canal, Culebra Cut, No. 2. Gray tuff with fragments of feldspar and basic (andesitic) lava. A gray agglomerate of small fragments closely pressed together; the cement is a fine cherty material with round grains of black ore; the feldspar crystals are often quite perfect, but the rock does not appear igneous.

(31) Panama Canal, Culebra Cut, No. 3. Dirty gray tuff with fragments of feldspar and basic lava. Same cement as 30.

(32) Panama Railroad. First hill west of Culebra station. Dirty gray tuff with black basaltic fragments.

(34) Culebra Cut, No. 3, Panama Canal. Gray tuff. The fragments are of andesitic lava.

(36) Barbacoas Formation at Barbacoas, Isthmus of Panama. In the hand specimen a white kaolin-like soft mass, which in the thin section is entirely without action on polarized light. It may be opal? The rock contains fragments of feldspar and shells, which have been replaced by the silica. The material is clear and isotropic in polarized light; contains curious round or elliptical bodies (lapilli?). It gives the test for a silicate, and fuses rather easily to a clear glass. Seems to be rhyolite pumice.

(37) San Pablo. Isthmus of Panama. A dirty gray marl-like rock with green spots. Contains sanidine crystals and augite. The feldspar is honeycombed with original glass inclusions. The cement is a greenish isotropic substance with frequent round or oval bodies, which are now replaced by silica. Probably an altered rhyolite pumice. Much like 23 and 36.

(39) Isthmus of Panama. Savannah, northeast of Panama, in a small hill. Tuff with andesitic fragments.

(41) Beach drift at Panama.

41. White porphyrite.

41 bis. Reddish rock with plagioclase phenocrysts. A decomposed porphyrite.

41a bis. Diabase or coarse basalt. This probably Culebra Summit = 41a.

41.1. White and red banded rock. Isotropic in slide. Silicified or cherty.

41.2 and 41.3. Porphyrite.

(43) Beach drift at Market Front, Panama. A fine grained greenish diabase porphyrite.

(44) Culebra, Isthmus of Panama. Dense greenish eruptive rock diorite porphyrite.

(46) Pebbles from Cut 1 at Culebra section. (See page 195.)

1. Chert.
2. Cherty tuff (with feldspar fragments).
3. Silicified tuff with large feldspar fragments.
4. Fine grained black shale siliceous with feldspar fragments.

(47) Gravels at junction of the River Chagres with the Obispo, Isthmus of Panama; brought down by river from unexplored interior.

1. Granite.
2. Green rock containing granite fragments; fine grained augite porphyrite.
3. Granite.
4. Fine grained quartz diorite.
5. Decomposed porphyrite.
6. Granite.
7. Basalt.
8. Basalt.
9. Very much altered quartz porphyry or rhyolite.
10. Quartz diorite porphyrite.
11. Augite andesite.
12. Epidotized diabase-porphyrite.
13. Black cherty siliceous shale.
14. Basalt.
15. Greenish porphyrite.
16. Dark gray augite porphyrite.
17. Quartz porphyrite. (See 27.)
18. Glassy hypersthene-andesite.
19. Decomposed quartz-porphyry.
20. Probably chert.
21. Granite.
22. White granophyric quartz-porphyry.
23. Granite.

24. Hornstone.
25. A fine grained reddish rock, which is composed of a microlithic glass with altered bands of microfelsite, much opal and chalcedony. Probably a trachytic glass.
26. Basalt.
27. Dacite or quartz-porphyrite.
28. Augite-andesite or basalt.
29. Further study required.
30. Decomposed dark gray augite-porphyrite.
31. Altered tuff, containing silicified feldspar and bisilicate fragments.

(51.2) and (51.3) Basalt. Paraiso.

(59) Near the Rio Grande River, Costa Rica. Hornblende andesite.

(59 bis) Melaphyre or Basalt.

(60) From the drift, Limon, Costa Rica. A greenish banded flinty looking rock; in the slide this is, however, all carbonate of lime, granular with large rounded areas which may be replaced shell fragments.

(64) San José, Costa Rica, from one mile south of suburb called San Miguel. Consolidated shell rock with clastic grains of feldspar. [Cretaceous limestone. — R. T. H.]

(65) Granite. Station east of Cartago called Siquieres, Costa Rica.

(66) Costa Rican railway between Limon and Cartago. (Label lost.) Hornblende-porphyrite or andesite. (66 bis) Melaphyre or basalt.

(68) Hypersthene-andesite, glassy. Between Cartago and Limon, Costa Rica.

(70) Various igneous rocks between Cartago and Limon, Costa Rica. Chalcedony.

(70) Altered tuff with fragments of basic eruptives, lavas.

3. Holocrystalline quartz-porphyry or granite-porphyry.

(71) Old igneous rocks in valley of San José, Costa Rica:

1. Melaphyre.
2. Enstatite porphyrite.

(72) Eruptives, valley of San José, Costa Rica. Decomposed mica-diorite-porphyrite.

(73) Lava in rim of crater Irazu volcano, Costa Rica. Basalt.

(74) Outer rim of the oldest crater of Irazu, Costa Rica. Basalt.

(76) Juanvinas, Costa Rica. Olivine free basalt, or augite-andesite.

(77) Loretta, between Las Animas and Pasqua, Costa Rica. Gray augite-porphyrite or holocrystalline augite-andesite.

(78) Irazu volcano, Costa Rica. Greenish gray augite-andesite.

(80) Between Cartago and Limon, Costa Rica. Hornstone? Further study required.

(81) Between Cartago and Limon, Costa Rica. Hypersthene-andesite.

(82) The summit between San Mateo and Boca, Costa Rica. A decomposed trachytic lava with some fragments of similar lava, probably not a water deposited tuff owing to the structure of the groundmass which shows fluidal structure; i. e. pyroclastic.

(91) Guallavas. Fine grained gray rock; a trachyte or trachytic andesite.

(92) Las Animas. Limestone tuff. Many fragments of plagioclase feldspar, quartz (rare), basaltic rock, and pieces of shells, with a calcareous cement.

(93) Above Las Animas. A scoriaceous dark gray enstatite-andesite, or porphyrite, with a brown glassy base.

(95) Las Animas. Limestone composed of fragments of shells with a calcareous cement and rare grains of quartz or feldspar.

(96) No. 13 Cliff. A gray limestone containing shell fragments. One slide shows these fragments with a granular calcareous cement and a rare grain of feldspar. The other has fragments of feldspar and basic lava in abundance, with calcareous cement, and shows, indistinctly, possible shell fragments.

(97) Massive No. 13 Cliff. Theralite. Composed of green augite, magnetite, biotite, olivine (serpentized) lathe-shaped triclinic feldspars, apatite sodalite; and zeolites representing the nepheline.

(98) Guallava. Fine grained gray rock. One slide contains shell fragments in a yellow calcareous cement. The other contains fragments of feldspar; calcitized bisilicates, basic lava in a calcareous cement, but no recognizable shell fragments.

(99) Venganza. Conglomerate of a dirty greenish gray color. The fragments are basic lava and feldspar.

(100) Pedro Fuego. Glassy basalt or augite-andesite.

(101) No. 13 Cliff. A shell limestone with quartz and feldspar fragments.

(102) Ballast Cliff. Dirty green tuff, containing fragments of feldspar, calcitized minerals (hornblende, etc.), and fragments of andesitic lava.

(103) No. 15 Cliff. Sandstone with shell fragments, and quartz and feldspar which suggest derivation from granitic rocks.

(104) Same rock as 102. Ballast Cliff.

(151) Typical augite-hornblende-andesite. Type of a surface lava.

With the preliminary report on all of your rocks, some additional notes are necessary. In your letter of October 29, you speak of the rock of the Culebra Summit as of importance. This is a coarse basalt or melaphyre corresponding in structure to many of the thick trap sheets of the Mesozoic diabases (Palisades, etc.). Its coarseness and lack of pores make it probable that it is either an intrusive mass, or comes from a very thick flow. In the same letter you speak of Nos. 19, 23, 24, and 36 as undoubtedly sedimentaries, and No. 36 as a tuff.

You will see from the notes that 19 contains fragments of volcanic rocks, 24 is a tuff; 20, 23, and 36 are the same. They have puzzled me somewhat; but I have concluded that they are composed of an acid rhyolitic pumice much like that found in beds in some of the Western States. Also 37.

You also say that 30 and 31 may be probably intrusive through Eocene clays. The hand specimens and slides of both rocks show that they are composed of fragments of volcanic rocks, or the corresponding minerals, in a siliceous cement which I cannot make out as intrusive.

Notes by Ahe Sjögren on the Eastern Section of Costa Rica.

I have shipped to-day to your address a box containing specimens and fossils collected along the line of the Costa Rican Railway from Las Animas to Las Lomas.

Enclosed you will find sketches (Plate VII.) from the railroad line between Las Animas and Las Lomas. They represent as far as I could make out all the stratified rocks exposed to view between the two points, and the intervening gaps are mostly filled up with the coarse conglomerate and boulders in clay that you noticed on our way down to Limon.

While not wishing to put forth any theory, I cannot help saying that the general features of the geology of the section seem perfectly plain. The stratified rocks have at one time been broken through by intrusions of molten matter, probably accompanied by a general elevation; the resulting ridges or peaks of igneous rock have then, by the tremendous erosion that takes place in these latitudes, been demolished, and the débris is now covering the stratified rocks, leaving it exposed in only a few places.

Some details at Las Animas have puzzled me very much. Just west of the stratified limestone and in the middle of the conglomerate, which here is very hard and compact, is another layer of lime dipping

the same, or about 45° west. Counting from above you would thus have:

Conglomerate,
Lime,
Conglomerate,
Lime,
Sandstone.

This might indicate two distinct periods of formation, but as the conglomerate on both sides of the lime seems to be entirely identical and the lime itself differs widely from the stratified lime farther east, and shows no signs of fossils, I would assume it to be of much later origin and due to infiltration.

The fossils I have been able to collect are not numerous, but I trust they will be sufficient to determine their age.

The reported coral reef at Aguas Calientes in Cartago, which was visited by request, proved to be calcareous tufa. The formation is going on to-day, and is due to precipitation of lime and magnesia from thermal springs in the vicinity. It looks at a distance somewhat like a coral reef.

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EXPLANATION OF THE PLATES.

PLATE I.

Map of the Isthmian Region.

PLATE II.

Map of the Caribbean Region.

PLATE III.

Map of Panama Bay.

PLATE IV.

Fig. 1. Topographic Profile across Costa Rica, natural scale.
Fig. 2. Natural Profile of Isthmian Region.
Fig. 3. Geologic Section across Isthmus of Panama, exaggerated vertical.

PLATE V.

Fig. 1. Amplified Details of Central Section.
Fig. 2. General Section and Profile across Costa Rica, exaggerated vertical.

PLATE VI.

Fig. 1. Continental Section, Isthmus of Panama, showing Relation of Land Surface to Submarine Platform.
Fig. 2. Costa Rican Section showing Amplification of the Caribbean Side, Protrusions of Igneous Rocks through the Tertiaries and Base Level Plain.
Fig. 3. Section of the Caribbean Slope, Province of Talamanca, by W. M. Gabb.

PLATE VII.

Sjögren Section of Caribbean Slope of Costa Rica.

PLATE VIII.

Typical Scenery, Isthmus of Panama.

PLATE IX.

Along Panama Canal, Caribbean Side.

PLATE X.

Panama Canal, cutting through Volcanic Tuff, at San Pablo.

PLATE XI.

Culebra Basin, looking East.

PLATE XII.

Panama Canal, Summit Section at Culebra, looking South.

PLATE XIII.

Panama Canal, cutting through Basalt, at Paraiso.

PLATE XIV.

Scene in the Valley of Cartago.

PLATE XV.

Crater of Poas Volcano.

PLATE XVI.

Boulder Clays, Rio Revantazon.

PLATE XVII.

Boulder Clays, Rio Revantazon.

PLATE XVIII.

Tobago Island.

PLATE XIX.

Crater of Turialba Volcano.

B. Meisel lith.

B Meisel lith

PANAMA ROAD
Taboguilla I.
Taboga I.
BAY OF PANAMA
Chame Pt.
CHAME BAY
Otoque I.
Bona I.
PERLAS ISLANDS
REY ISLAND
SAN JOSE
St Elmo I.
ST ELMO BAY
Galera I.
NORTH BAY
DARIEN HARBOR
Buey Bank
SAN MIGUEL BAY
Carachine Pt.
SOUTH BAY
San Jose Bank
Escarpado Pt.
Chiru I.
Antoine Pt.
PARITA BAY
Lisa Pt.
GULF OF PANAMA
Caracoles Pt.
Iguana I.
Cape Mala
Pinas Pt.
Cocalita Pt.
Morro Puercos
80°
79°
8°

1. Continental Profile across Costa Rica, from Cape Blanco to Port Limon.

2. Continental Profile across the Isthmus and Gulf of Panama.

3. Geological Section across the Isthmus of Panama.

VERTICAL SCALE EXAGGERATED.

B Meisel lith

CULEBRA SECTION
MATA CHIN SECTION
PANAMA SECTION
BARBACOAS SECTION
600'
500'
400'
300'
200'
100'
Sea Level
Rio Grande
Miraflores
Pedro Miguel
Pariso
Culebra Water Shed
Cerro Culebra 620'
Limit of Stratified Clays
Empire Station
Dolerite
Limestone Cut
Las Cascadas
Upper Obispo
Hornblend Augite Porphyrite Boulders
Bas Obispo
Junction of Charges & Obispo
C. Combay 1000'
Mata Chin
C. Ceravali 800'+
Gorgona
Culo Seco 630'
Juan Grande
Cerro Jira 480'
Mamei
San Pablo
Barbacoas
Miles 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21
Kilometers 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37
DOLERITE
TUFA (BASALT FRAGMENTS)
Sounding to Sea Level
Sounding to Sea Level
ERUPTIVE AUGITE PORPHYRITE
TRACHYTE TUFA
SILICIFIED TUFA
AUGITE ANDESITE
AUGITE PORPHYRITE
OLIVINE BASALT
BASIC TUFA
BASALT
METAMORPHOSED CLAYS AT CANAL LEVEL
TRACHYTE TUFA
STRATIFIED CLAY AGE INDETERMINATE a
EOCENE CLAYS b
EOCENE LIMESTONE c
RHYOLITIC PUMICE d
BASIC TUFAS e
MASSIVE IGNEOUS f
MATA CHIN BOULDERS g
ANCIENT SEDIMENTARY IGNEOUS DEBRIS h
Turri Alba Volcano Probable Height 11500'
CANON OF THE REVANTAZON
Turri Alba Station 2200'
LINE OF RAIL ROAD
GRANITE BOULDERS
Swamp Level Alt 35'
GRAPE KEY
Las Animas 1700'
Torito 1300'
Per Alto
SCALE VERTICAL 1/4 inch = 1000 feet. HORIZONTAL 1/4 inch = 1 mile.
Las Lomas 600'
La Junta 250'
Siquires 220'
Madre de Dios 170'
Salse Puedes 100'
Matina 35
Keith 10
PORT LIMON
B Meisel

HILL-ISTHMUS OF PANAMA. PL. VI

B Meisel lith

Las Animas
Pedro Fuego Fold
Augite Andesite
Las Animas
Pedro Fuego
Guallava
1700'
1600'
1500'
Guallava
Vicksburg (Lower Oligocene)
1400'
Torito
1300'
Igneous
Lime
1200'
1100'
Clay
1000'
Sandstone
Tufa
Bonilla Cliff
(Upper Oligocene)
Ballast Cliff
900'
Coarse Lime Sandstone
Granitic Derived Sediments
800'
Coarse Conglomerate Boulders in Clay
13 Cliffs
700'
Coarse Lime Conglomerate
600'
Venganza
La Lomas

CRATER OF TURI ALBA VOLCANO.

TYPICAL ISTHMIAN SCENERY.

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ALONG PANAMA CANAL, CARIBBEAN SIDE.

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CUT THROUGH IGNEOUS TUFA, SAN PABLOA.

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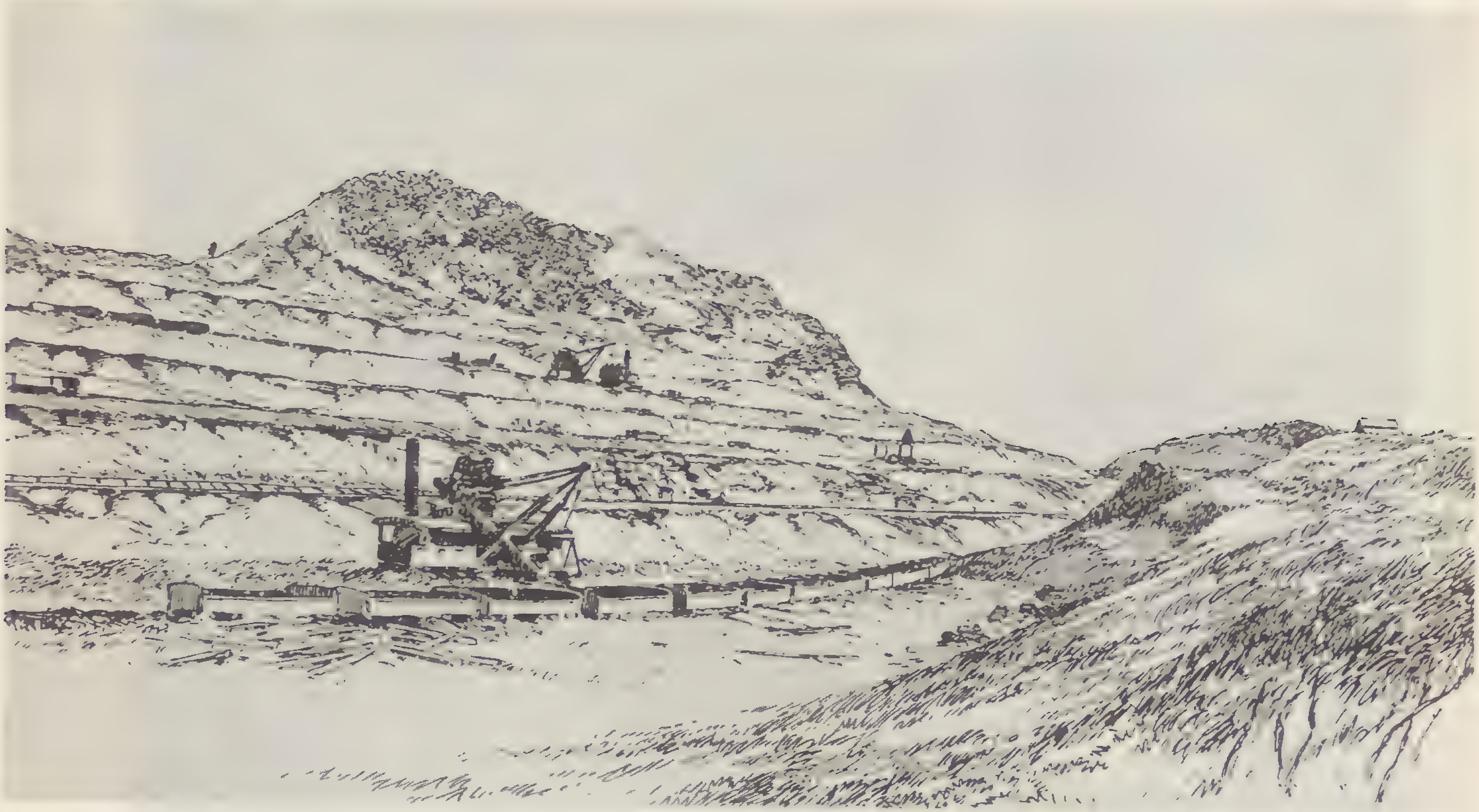
NORTH VIEW OF CULEBRA BASIN.



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CULEBRA SUMMIT.

THE HELIOTYPE PRINTING CO. BOSTON

MASSIVE BASALT AT PARAISO.

THE HELIOTYPE PRINTING CO. BOSTON

SCENE IN VALLEY OF CARTAGO.

THE HELIOTYPE PRINTING CO. BOSTON

CRATER OF POAS VOLCANO.

THE HELIOTYPE PRINTING CO. BOSTON

BOULDER CLAYS, RIO REVANTAZON.

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BOULDER CLAYS, RIO REVANTAZON.

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TABOGA ISLAND, PANAMA BAY.

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